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Highway Engineering

144 Illustrations

By

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HIGHWAYS
CITY SURVEYING

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NOTE.—This volume is made up of a number of separate Sections, the page numbers of which usually begin with 1. To enable the reader to distinguish between the different Sections, each one is designated by a number preceded by a Section mark (§), which appears at the top of each page, opposite the page number. In this list of contents, the Section number is given following the title of the Section, and under each title appears a full synopsis of the subjects treated. This table of contents will enable the reader to find readily any topic covered.

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CITY SURVEYING, § 63

HIGHWAYS

(PART 1)

HIGHWAY SURVEYING AND MAPPING

PRELIMINARY INVESTIGATIONS

LOCATION, TOPOGRAPHICAL FEATURES, AND TRAFFIC SURVEY

1. Factors Requiring Investigation.—Before it is practicable to design a system of highways or a given road or street in a satisfactory and economical manner, it is necessary to make thorough preliminary investigations. Such investigations have always been considered an essential factor in railroad engineering, but their economic importance in highway work has not been universally recognized.

Preliminary investigations will vary in detail depending upon the character of the highway or system of highways to be designed. All investigations should cover the following fundamental factors: Location, foundation, width, drainage, esthetics, climatic conditions, traffic census, normal and abnormal speed of various classes of traffic, the traffic regulations in force, the probable change in the character and amount of traffic, topographical and geological structure and features, the condition and character of cross-roads or cross-streets, the character of the existing surface, the possible diversion of traffic, the

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months available for construction, local highway materials, the methods of maintenance in vogue, and the character of available plant equipment and labor.

2. Location.—Grades, curves, distances, cost of construction, and serviceability to commercial, industrial, agricultural, and social interests are important functions of location. In the case of roads, a proper consideration of the factors mentioned requires extended investigations, as it is practicable in many cases to consider several locations. Streets are more definitely located than roads. However, grades should receive careful consideration, as the advantages resulting from grade reductions are in some cases worth many times the property damages incurred.

3. Topographical Features.—In order to select the most advantageous route, certain information must first be obtained regarding the physical features of the country to be traversed. The operation by which this information is procured is called the reconnaissance, or exploration. This is effected by either walking or riding over the proposed route. With a good contour map, the work is much facilitated, because the approximate position of the line may be determined with reasonable certainty before going into the field, and notes can be made on the map of the different lines from which a selection may afterwards be made.

The information to be sought in the exploration includes: (1) The general features of the country; that is, the general positions of rivers, streams, roads, trails, railroads, villages, valleys, summits of hills, and gaps or passes; (2) the geological features, the character and inclination of the strata, and the sources from which materials may be obtained for the construction of the proposed road; and (3) the probable requirements of the districts passed through.

The instruments employed in the reconnaissance are the pocket compass for ascertaining directions, and the aneroid barometer and hand level for obtaining approximate elevations. Distances are estimated by the eye or with the aid of a pedometer.

If the character of the country is such that an ordinary reconnaissance will fail to give the desired information, an exploration may be made by means of transit and stadia.

4. In reconnoitering a tract of country, the first feature to attract the observer's attention is the apparently endless combination of irregular and undulating forms composing the surface. On close examination, it will be perceived that two classes of configuration, or form of the surface, prevail, even in the most irregular country, namely, the hills and the valleys.

An acquaintance with the nature of the configuration will very much lessen labor and time of reconnaissance. It will be noticed that the country is intersected in various directions by main valleys, through which flow the main watercourses or rivers, which increase in size as they approach the point of their discharge. Toward the main rivers, smaller rivers approach on both sides, running right and left through the country, and into these, again, enter still smaller streams and brooks. The streams separate the hills into branches or spurs, which have approximately the same course as the waterway, and the ground rises in every direction from the watercourses, forming slopes, the intersections or apexes of which form ridges of greater or less height; these ridges slope up to the tableland into which their summits merge.

The watercourses thus mark not only the lowest lines, but also the lines of longitudinal slope. The position of the tributaries to the larger streams indicates generally the points of greatest depression in the summits of the ridges, hence the points at which lateral communication across the tableland separating contiguous valleys can be most easily made. If two or more streams diverge from any point, that point will be the highest part of the region; while, if several streams converge to a common point, that point will be the lowest.

The amount of work that it is necessary to expend on a reconnaissance will depend on the difficulties attending each particular case, but neither time nor labor should be improperly economized, as a careful reconnaissance will save much future expense in the location, construction, and maintenance of the road.

5. Traffic Surveys.—In connection with the preliminary investigations, an engineer must always consider the change in the character and amount of traffic that is likely to occur after the improvement of a highway. The importance of an estimate of probable traffic cannot be overemphasized.

Various classifications of the traffic have been proposed from time to time. All classifications have been dependent primarily on the effects of various types of traffic on the several kinds of roads and pavements. The essential elements of any classification of traffic may be stated as follows: (*a*) The making of a distinction between horse-drawn vehicle traffic and motor-vehicle traffic; (*b*) a division of each of these classes of traffic into passenger and commercial traffic; (*c*) a subdivision of commercial traffic into loaded and unloaded vehicles; (*d*) the determination of the weight per linear inch of width of tire of all types of commercial traffic, a factor of the utmost importance in the design of the substructure of the road; (*e*) a subdivision of the two classes of horse-drawn vehicle traffic dependent upon the number of horses; (*f*) a subdivision of motor-car traffic upon the basis of weight and speed, since in many instances the greatest damage to a broken-stone road is caused by seven-seat touring cars, limousines, or landaulets traveling at speeds of 40 to 60 miles per hour; (*g*) a subdivision of motor-truck traffic upon the basis of weight and speed; (*h*) provision for extraordinary character of local traffic. For example, traction engines hauling trailers may be common, while in other cases motor-bus traffic may be a regular and an important feature; or special types of commercial traffic such as ice wagons, mill drays, etc., may use the highway.

6. The classification given in Table I was recommended by the Special Committee on Materials for Road Construction, of the American Society of Civil Engineers. It covers satisfactorily average traffic conditions.

7. Methods of Taking a Traffic Census.—The method selected for taking a traffic census will be influenced by the amount of time at the disposal of the engineer and the kind, amount, and distribution of the traffic to which the highway in

TABLE I

CLASSIFICATION OF TRAFFIC

	Commercial Vehicles			No. of Passenger Vehicles
	No. Empty	No. Loaded	Estimate (in pounds) of Maximum Load per Inch of Tire	
One-horse vehicles.......				
Two or three-horse vehicles..................				
Four or more horse vehicles..................				
Motor cycles............				
Motor runabouts				
Motor touring cars (open or closed).............				
Motor busses...........				
Motor trucks...........				

question is subjected. As the primary object of any traffic census is to secure data covering both normal and abnormal traffic of all classes, it is essential to incorporate in a plan definite provision for securing such information rather than to depend on a haphazard selection of days for making observations to furnish the facts. Some of the varying local conditions are the following: (*a*) Exceptional horse-drawn vehicle traffic, consisting of produce wagons, between the hours of midnight and 6 A. M. during certain seasons of the year; (*b*) market days, fair days, and other special events in connection with which both pleasure and commercial traffic may be excessive; (*c*) periodical heavy shipments by special industries using the highway in hauling raw material or in shipping manufactured articles; (*d*) through traffic at certain periods of the day, week, or year, as, for example, motor-car traffic between residential communities or summer colonies and cities.

In many cases it is essential to make a distinction between the following three classes of traffic: Normal winter traffic, normal summer traffic, and abnormal traffic. It should be borne in mind that from the standpoint of the proper design of the highway, it is necessary to know approximately the total yearly traffic, which includes both the normal and abnormal traffic, and also the amount of abnormal traffic of various types at different periods of the year.

8. The following three comprehensive methods for taking traffic census throughout the year have been used: (1) The traffic is counted and recorded in periods of 6 or 7 consecutive days. (2) The days for counting and recording are distributed throughout a given season by starting on a given day of the week, for example, on Monday, then taking the traffic on the Tuesday of the following week or at an interval of 15 days, and so on during the season. (3) For the season from April to October, inclusive, the traffic could be taken during four periods of 3 days each; one period being in April, May, or June, one in July, one in August, and one in September or October. As local conditions may dictate, either Friday, Saturday, and Sunday, or Saturday, Sunday, and Monday could be taken, thus insuring information relative to the usual abnormal Sunday motor-car traffic, while the Friday or Monday traffic would give a fair indication of the normal week-day traffic. In the months from November to March, inclusive, two 3-day periods would be taken in certain cases; one in November or December, the other in February or March. This distribution of the periods would furnish statistics of the normal traffic in this season, and would also afford opportunity for a study of traffic detail and the condition of the highway during the winter season.

9. The number of consecutive hours during which the traffic census should be taken during the day will depend upon local conditions and the time of the year when observations are made. In many cases, especially in municipalities, 24 hours will be absolutely necessary; while in certain cases 8 to 15 hours will be satisfactory. It must be borne in mind that the facts

ascertained are used only as a basis for an estimate of traffic and hence minute detail should not be obtained at unwarranted expense.

What has previously been said in regard to taking a traffic census outside of cities applies to methods that may be adopted for this purpose within the cities. However, the method to be adopted in any case will vary, depending upon local conditions. An investigation of the business interests situated on the street, the merchandise that is handled and the general routes taken by traffic from the railroad centers or docks must be made, before it is possible to decide intelligently on a plan for taking the census. In residential districts, the problem is more simple and the method used ordinarily would be very similar to that proposed for highways outside of built-up districts.

SURVEYS FOR ROADS

LOCATION AND USE OF TRANSIT LINE

10. General Scope of the Work.—Road surveys do not demand the same degree of accuracy as is required in surveys for streets in cities, mainly because the property bordering on the highway is of less value in rural districts than in cities. The surveys are not usually tied in with any system of points previously established by triangulation or by closed traverses. A survey on one road may be entirely independent from that on another road. Adjoining surveys on the same road should be connected with each other, but it is not essential that the stationing should be continuous.

The surveying of a road that follows an existing highway, is the simplest form of highway surveying. The alinement of the old traveled way, however, may be greatly improved by a proper choice of tangents to eliminate the irregularities of the old line, and by flattening out or widening sharp curves. Changes of this character can generally be effected within the boundaries of the highway.

The surveys for roads on entirely new lines are carried out in about the same manner as in railroad work. The United States Coast and Geodetic Survey, in conjunction with the various states of the country, has prepared topographic maps that give contours that are useful in locating roads. If the proposed location of the road by means of such maps is studied with sufficient care, it may be unnecessary to make more than one survey. If a map cannot be obtained, a thorough study of the locality should first be made, as in railroad work, and then one or more survey lines must be run before the best route can be determined, the number of lines depending on the unevenness of the country.

11. Transit Line.—A complete road survey should include the running of a transit line, from which the location of all topography is made. It should also include the elevations showing the profile of the center line of the road and the form of the earth's surface for a certain width on each side. This width should be sufficient to include all of the construction that will be done in connection with the improvement of the road. The transit line may or may not coincide with the proposed center line of the new road.

12. The Transit Line as Reference Line.—In some instances the transit line may serve only as a *reference line* on which the rest of the location is based, and as a *working line* from which the proposed work can be staked out. From the standpoint of convenience this method has several advantages. The traffic conditions may be such that the work will be constantly interrupted, unless the line is run along one side of the highway, rather than near the center. It is the practice in some cases to stake each 50- or 100-foot station on the line as the survey is being made, the line being far enough removed from the center so that the stakes will not be disturbed during construction. The line of stakes serves as a convenient reference for any further staking necessary during construction. In some cases where a car track is located in the road, the transit line may be made to coincide with the line of one of the rails. If this is done, it is a very easy matter to relocate the line at a later

time, without the use of a transit, for purposes of measuring up the work or resetting stakes and securing additional information.

13. Transit Line Used as Center Line.—The surrounding topographical conditions will govern the advisability of trying to obtain a field location of a line that will be the best one from every standpoint. In many cases too much time is spent in the field in accomplishing this result. If the country is generally flat, and if proper cross-section levels are taken, it will be possible, by studying the maps alone, to determine upon a final center line which, in places, might be several feet to either side of the transit line without involving any appreciable error in the elevations of the stations. On the other hand, if the country is extremely rough, and a change of line from the transit line is made in the office, another trip by the field party may be necessary in order to obtain information relative to the change. A material departure of the final center line from the transit line is, however, likely to change the stationing. Considered from the standpoints of accuracy and expeditiousness of office work, the best transit line is the one that approaches more nearly the final center line of the road.

14. Location of Stations.—The transit line, which is usually made up of tangents and curves, should start from a definitely located initial point, which may be a point on some previous transit line, or some chosen point carefully tied in with permanent objects.

When the external, or deflection, angle between two tangents is less than 10 degrees, the distance between stations may be measured along the tangents without appreciable error, although a slight curve may be built at the intersection; when the external angle between the tangents is over 10 degrees, it will be necessary to use a curve and compute its length in order to locate the stations correctly. On the tangents, the stations are located either every 50 or every 100 feet, depending on the character of the topography and the accuracy desired for the estimate of grading. There is a variety of methods of locating the stations on the curves. In the case of short curves the actual

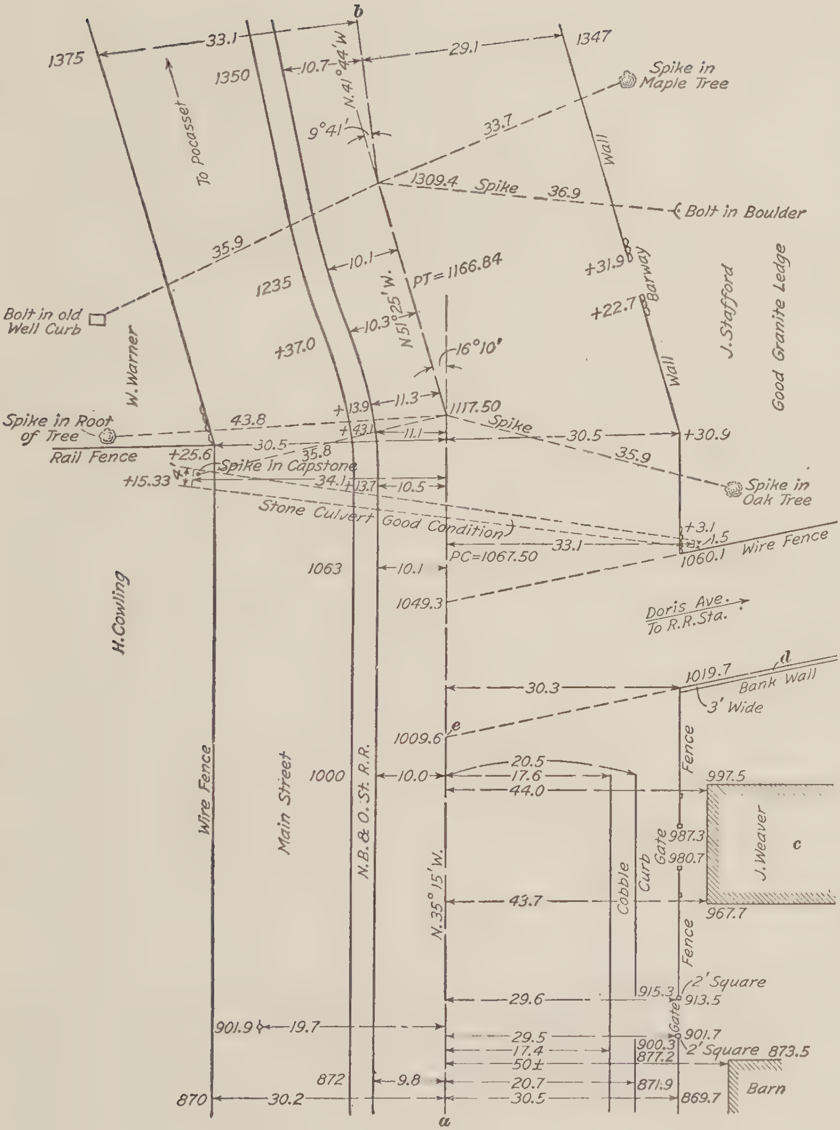
length of the arc may be computed and the curve laid out by eye, guided by the external point, the P. C. (point of curvature), and the P. T. (point of tangency). In the case of long curves, however, it is more convenient to lay out the curve by deflection angles.

It should be borne in mind that any points established on the line are likely to be removed or covered up during the construction, so it is important that the points at the intersections of the tangents should be carefully tied in to objects that are permanent and readily accessible. If this part of the work is well done and good sketches are made, showing the tie distances, it will save considerable loss of time at a later date, when it is desired to rerun the line.

15. Field Party and Equipment.—A small transit party may comprise one transitman and three assistants who will serve at various times as either rodmen or chainmen. The equipment may consist of the following instruments: One transit; one 100-foot steel tape, graduated to feet and hundredths; one 50-foot metallic tape; one self-reading level rod, equipped with a target; two range poles, pins, plumb-bobs, spikes, tacks, chalk, and axe.

In New York State, a survey party usually consists of the following: One surveyor in charge, an instrument man, five men as rodmen, chainmen, and axemen, making a total of seven in the party. The equipment includes a transit and a level; two steel chain tapes, 100 feet long; two sighting poles; three plumb-bobs; two level rods; three 50-foot metallic box-tapes; two hatchets; crayon; pencils; scales; note-book covers and sheets; copy of official general instructions; blanks for reports, expense accounts, vouchers, hotel bills, etc. Nails, spikes, cloth, and similar articles are bought in the field. All useful data of previous surveys in the vicinity are carried; these include bench marks (B. M.'s), transit point ties, etc., which are copied before going into the field, as the original notes should not be removed from the office.

16. Running the Line.—The chief of party should first carefully plan out the location of the tangents and intersection



b
1375
33.1
1350
10.7
N.41°44'W
29.1
1347
Spike in Maple Tree
To Pocasset
9°41'
33.7
Wall
1309.4 Spike
36.9
Bolt in Boulder
35.9
10.1
1235
PT=1166.84
+31.9
Barway
+22.7
J. Stafford
Good Granite Ledge
Bolt in old Well Curb
W. Warner
+37.0
10.3
N.51°25'W.
16°10'
Wall
+13.9
11.3
1117.50
Spike in Root of Tree
43.8
+43.1
11.1
Spike
30.5
+30.9
Rail Fence
+25.6
30.5
35.8
35.9
Spike in Capstone
+15.33
34.1
+13.7
10.5
Spike in Oak Tree
Stone Culvert Good Condition
+3.1
1.5
33.1
Wire Fence
1060.1
1063
10.1
PC=1067.50
1049.3
Doris Ave. To R.R.Sta.
H. Cowling
1019.7
d
Bank Wall
30.3
3' Wide
1009.6
e
Fence
20.5
997.5
1000
10.0
17.6
44.0
Wire Fence
Main Street
N.B. & O. St. R.R.
987.3
Gate
980.7
J. Weaver
c
Cobble Curb
N.35° 15'W.
43.7
967.7
Fence
2' Square
29.6
915.3
913.5
901.9
19.7
29.5
Gate
901.7
900.3
17.4
877.2
2' Square
873.5
872
9.8
50±
20.7
871.9
Barn
870
30.2
30.5
869.7
a

Fig. 1

points, as shown in Fig. 1, which represents a portion of transit notes relating to a highway that is to be laid out along an existing railroad. The transit line is shown at *a b*. The directions of its tangents are indicated by their magnetic bearings and the numerous offsets are indicated. The latter are taken from objects situated near the proposed transit line, and running in a direction more or less parallel to the line, such as the track rails, fences, etc. If the transit line is to be used simply as a reference line, the same care will not have to be exercised as when it is desired to make the transit line coincide with the final center line of road.

17. The transit should be set up at the intersections of the tangents; from these points the tangents can be run out in either direction. The angle between the tangents should be turned off at least twice and the mean value taken. The magnetic bearings of the tangents should also be taken as a check. The angle read may be the angle *a*, Fig. 2, included between the two tangents *c d* and *d e*, or it may be the supplement *b* of this angle, included between the extension *d f* of the tangent *c d* and the tangent *d e*, this angle being known as the *intersection angle.* Because the intersection angle will be used in mapping the survey, it will be more convenient for the office work if that angle is the one read and recorded in the notes. The length of each tangent is determined with the steel tape, the measurement being made to the nearest hundredth of a foot. Starting from the initial point, the 50- and 100-foot stations are marked on the tangents by pins or by spikes. If the angle at the intersection *d*, Fig. 2, is large enough to warrant the use of a curve, the stations of the P. C. and P. T. of the proper curve should be computed and marked on the line.

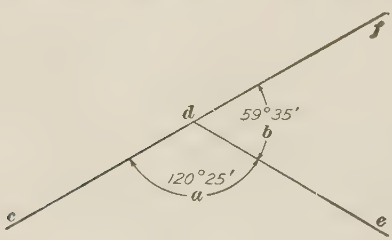


Fig. 2

TAKING AND RECORDING TOPOGRAPHY

18. Taking Topography.—The topography includes the shape of the ground and the locations of all objects, such as houses, walls, fences, gutters, curbs, culverts, bridges, catch-basins, trees, monuments, edges of traveled ways, poles, ditches, etc.; in fact, any object that occurs within the limits of the survey that will be of importance in designing the road. Methods of taking topography will be considered more in detail further on.

All topography is located with reference to the tangents, as shown in Fig. 1. One of the easiest and quickest ways to locate the greater part of the topography is by perpendicular offsets from the transit line. This method of location also simplifies the plotting very much. For example, in locating such topographic details as fences, walls, and curbs, it is sufficient to record the points on the transit line opposite which they begin and end; these points will define their alinement. The *offsets* are the perpendicular distances measured from these points on the transit line to the points of the objects previously noted. Thus, the position of the building at *c*, Fig. 1, is located by the offsets at two corners, reading, respectively, 43.7 and 44.0 feet, opposite stations 967.7 and 997.5. The perpendicular direction of the offsets will be usually estimated by eye, and if the object is not too far away the results obtained are sufficiently accurate. The offsets and the plus distances measured from the 50- or 100-foot stations, previously established along the tangent, may be conveniently read by means of a metallic tape.

Offsets and plus distances for location of objects should never be measured closer than the nearest tenth, and in many instances where the topography is not well defined, the nearest foot will be sufficient. Measurements should be taken to the face of walls, fences, etc.

19. When a P. C. is reached, the location of the topography should be made from the tangents. The distances along the tangent can be recorded as *plus distances* from a P. C. to the

point of intersection. Starting again at the intersection, plus distances from the latter can be employed until the P. T. is reached. Beyond the P. T., points for offsets are located by the regular line stations and pluses from them. Highway lines and property lines that intersect the transit line at an angle may be located by noting the point on the transit line at which the line in question, if prolonged, would intersect it, and also noting perpendicular offsets to the corners from points on the transit line opposite these corners. For example, the wall at *d*, Fig. 1, is located by extending the wall line until it intersects the transit line at *e*. The perpendicular offset from the corner of the bank is seen to be 30.3 feet at station 1019.7.

In places of importance, such as squares and villages, where the location by offset methods might be difficult, the topography can be readily obtained by taking angles and distances to the various points.

20. Recording the Notes.—The notes should be recorded by the chief of party and should begin at the bottom of the page and continue to the top. For the sake of clearness, it is better to sketch the line as it actually occurs rather than to represent it by a straight line up the center of the page. A sample page of transit notes is shown in Fig. 1, in which many of the points above mentioned are illustrated.

21. Levels.—The information required for the location of topographic features is completed by taking what are commonly known as *cross-section levels*. These show the elevations of the surface on lines taken at right angles to the tangents at the various stations and at points where there is a sudden change in the form of the earth's surface. From the information thus obtained, both the profile of the transit line and the shape of the earth's surface at definite intervals along the transit line can be plotted. The necessary levels may be taken by the party that runs the transit line or by a separate party. In the first case the line and location of the topographic features can be completed before starting the levels, or the levels can be taken on the different portions of the line as they are run out, and thus the whole of the work be completed as it progresses.

22. Bench Marks.—In many states, lines of levels have been run starting from a U. S. Government bench mark (B. M.), and other bench marks have been established on these lines at various points, so that it is not a difficult matter to get a tide-water datum for the levels on any road. If this has not been done, the datum must be assumed. If a good contour map is available, a datum may be assumed that will approximate the actual height of the ground above tide water. Otherwise, any datum can be assumed, so long as it is high enough not to require the use of minus elevations in the survey. Points for bench marks should be of a stable and permanent character, and their locations should be clearly described so that they may readily be found at any time. At least one permanent bench mark should be established every 1,000 feet along the survey.

23. Running the Levels.—The levels may be taken either with a transit or with a level. The transit, if in adjustment and carefully used, is sufficiently accurate for the work, but it should not be used in establishing a long line of bench levels. When the rod is held on a B. M. or on a T. P. (turning point), the target should be set as a check and the rod read to the nearest hundredth. In obtaining the elevations of the earth's surface, it is not necessary to use the target or to read the rod closer than the nearest tenth. The measurements of the plus stations and offsets to points at which levels are taken may be made by means of a metallic tape. The chief of party takes notes, one man runs the instrument, another holds the rod and the zero end of the tape, and the third man holds the other end of the tape and calls off the distances to the points at which the rod is held.

24. Enough points should be taken to show correctly the shape of the earth's surface. This may be accomplished by taking elevations at each 50- or 100-foot station along the transit line, one elevation being taken on the transit line and a sufficient number of elevations being taken on lines perpendicular to the transit line at these stations to define the changes in slope of the earth's surface. The elevations of car tracks, curbs, gutters, edges of traveled way (T. W.), bottoms and tops of banks,

together with their distances from the transit line, should be taken in all cases. Care should be taken to extend the levels on either side of the transit line sufficiently far to cover the proposed construction, and where heavy cuts or fills are likely to be made, the chief of the party should use special care in selecting the position for the bench marks.

25. In addition to taking levels, as described, at every 50- or 100-foot station along the transit line, elevations should also be obtained in the same manner at those stations on the transit line which mark a change in slope. Center-line profiles should

(Left-Hand Page)					(Right-Hand Page)
(Description of Survey)					J. H. Smith, Inst. 5-9-'21 F. Grant C. Jones
Sta.	B.S.	H.I.	F.S.	Elev.	Remarks
B.M.	3.40	53.40		50.00	Nail in Stump 80' W. Sta. 0+00.
0+00			5.60	47.80	C
			5.80	47.60	7.5 Left
			6.40	47.00	12.0 T.W.
			6.70	46.70	11.5 R.T.W.
			7.10	46.30	17.0 Rail
0+50			7.60	45.80	C
			8.10	45.30	12.5 T.W.
			8.40	45.00	10.0 R.T.W.
			8.70	44.70	16.0 Rail
			9.00	44.40	25.5 Ledge
T.P.	6.30	49.60	10.10	43.30	C.B. House 50' W. Sta. 0+50
1+00			10.30	39.30	C.

FIG. 3

also be run along every intersecting street and driveway for a distance of at least 200 to 300 feet from the transit line. Elevations should be taken at the corners of houses, at the ground line, and at the sill or corner board (C. B.) in cases where there is any possibility of the improvement disturbing the property.

The elevations of the tops and bottoms of all culverts and drains at both ends should be determined. A line of levels should also be run along the ditches to culverts at both the inlet and outlet ends. In the case of bridges, elevations should be taken of bridge seats, bridge floors, tops of parapet walls, high-water marks, points that will define the stream bed at the bridge and at points along the banks of the stream above and below the bridge.

Check levels should be run between the turning points and the bench marks at the end of each day's leveling, or, if the work is done from time to time, the check levels should be run at the completion of each portion of the work.

26. Recording of Level Notes.—A method of recording the cross-section level notes is shown in Fig. 3. In the column headed Elev., the levels are carried down, starting from the top in a manner similar to that commonly used in the recording of level notes. In the column headed Remarks, the distance of the point from the transit line is given and also a description of the point. The abbreviations employed have the following meanings:

Sta. = Station.
B. S. = Backsight.
H. I. = Height of instrument.
F. S. = Foresight.
T. P. = Turning point.
B. M. = Bench mark.
T. W. = Traveled way.
C. B. = Corner board.
R. T. W. = Right, Traveled way.
C. = Center, meaning that this point is on the transit line.

27. Staking of Grades.—Two methods of staking grades are in common use. One method is to drive stakes at the time the survey is made. In this case the ground elevations at the stakes and elevations on tops of the stakes are taken. Two lines of stakes are used, one line being driven on each side of the transit line. The stakes are driven far enough away from

the transit line so that they will not be disturbed during construction. Along tangents, the stakes are placed at intervals of either 50 or 100 feet. On curves they may be spaced as close as 25 feet, depending on the length and nature of the curve. When the grade of the road has been established, the grade elevations at the stations, where the stakes are driven, can be determined in the office. The difference in height between the established grade and the tops of the stakes is recorded on a sheet which is sent to the inspector on the work, who is thus able to define the grade.

28. In the other method, stakes are not driven until after the grade has been determined in the office. The stakes are then driven as before and notches are cut on them, generally placed so as to be at the grade of the center line of the roadway to be constructed or at some even-foot distance above or below grade. The stakes should be at least 2 feet long, and approximately 2 inches square. In this method, all information is marked on the stakes. The sides of the stakes facing the center of the road are marked with the distance of the notch above or below grade. On the outside faces of the stakes on one side of the road is marked the station. On the outside faces of the stakes on the other side of the road is marked the distance from this face of the stake to the center line of the road. It may be necessary when a stake comes in a driveway or at some other point where traffic must pass over it, to drive the stake flush with the ground. Stakes so driven are recorded as flush stakes, and the grades are referenced to the elevations of their tops. A sheet showing the relation between the flush stakes and the grade should be given the inspector.

Some engineers use only one line of stakes. When one line of stakes is used, all information is marked on three faces of the stake, one face being left blank. The side of the stake facing the center of the road is marked with the distance of the notch above or below grade, and on the opposite side is marked the distance from this face of the stake to the center line of the road. On the side of the stake facing the direction of the survey is marked the station and the opposite side is left blank.

29. Recording Grade Notes.—In Fig. 4 is shown a sample page of notes made as a record of marking grade stakes according to the method explained in Art. 28. The elevations given in the fifth column are those of the grade at the center of

Sta.	B.S.	H.I.	F.S.	Elev.	R.	L.
B.M.	Bolt in Side	Boulder Sta. 531	East ±	50.0		
	4.53	54.53				
5 + 00			7.28	47.25	6.28 1' ↓	7.28 Gr.
5 + 50			7.68	46.85	9.68 2' ↑	8.68 1' ↑
6 + 00			8.08	46.45	8.08 Gr.	9.08 1' ↑
6 + 50			8.60	45.93	9.60 1' ↑	7.60 1' ↓
T. P.			12.21	42.32		
	3.17	45.49				
7 + 00			1.92	43.57	3.92 2' ↑	4.92 3' ↑
7 + 50			3.24	42.25	3.24 Gr.	3.24 Gr.
8 + 00			5.62	39.87	6.62 1' ↑	5.62 Gr.

Fig. 4

the road and are obtained by computing the center-line grade. Knowing the height of instrument, the rod reading that would give a grade elevation is determined by subtracting the elevations in the fifth column from the height of instrument, the results being entered in the foresight (F. S.) column opposite their respective stations. The rod is then held at the grade stake and moved up or down alongside the stake until a rod reading is obtained that is the same as that called for in the column F. S., or which differs from it by an even number of feet. A notch is cut in the stake at the point giving the reading, and the reading obtained is entered in either of the last two columns, the one headed *R* being for stakes on the right of the road and that headed *L* for those on the left. A rod reading smaller than that in the column F. S., as, for example, 6.28 in column R., indicates that the notch in the stake is higher than the grade. In this instance it is 1 foot higher and the stake would be marked *1'* with an arrow pointing downwards in the manner indicated in column R., thus indicating that the grade is 1 foot below the notch.

A rod reading greater than the reading in column F. S., as in the case of 9.68 in column R., indicates that the grade is above the notch in the stake, in this case 2 feet, and the stake would be marked *2′* with an arrow pointing upwards in the manner shown in column R.

When a rod reading from a notch on a stake is the same as that in column F. S., the grade is at the notch and the stake is marked *Gr*

30. Setting Slope Stakes.—Slope stakes, defining the ends of the slopes on either side of the road, should be set where the cuts or fills are heavy. The position of slope stakes can be most easily determined by measuring the distances on the plotted cross-sections from the center line to the edge of the slope. These distances can then be laid off in the field at their respective stations.

MAPPING SURVEYS

PLANS, PROFILES, AND CROSS-SECTIONS

31. Plan.—The survey plan may be plotted on a continuous roll of detail paper. The scales generally used are 40 or 50 feet to the inch. The transit line is first laid out on the sheet. This may be plotted by either of two general methods. One of these, known as the *coordinate method*, consists of computing and laying off the coordinates of the several points of intersection of the tangents with reference to one of the tangents as a base line. The tangent selected as the base line is drawn parallel with one edge of the paper and in such a position on the sheet that the transit line, when completely drawn, will not run outside of the limits of the sheet.

This method is illustrated in Fig. 5, where the tangent $i\,j$ is selected as the base line and is produced toward the points b and q. The rectangular coordinates to the different intersection points are computed with reference to this line as a base. For example, in Fig. 5, if the angle that $l\,j$ makes with the base line is A, the abscissa $j\,k = j\,l \cos A$ and the ordinate $l\,k = j\,l \sin A$.

Other coordinates are found in a similar manner. After computing the positions of the points *b*, *c*, *e*, *g*, and *k*, perpendiculars are drawn from the points and the corresponding ordinates are plotted, giving the points *a*, *d*, *f*, *h*, and *l*. Where points are

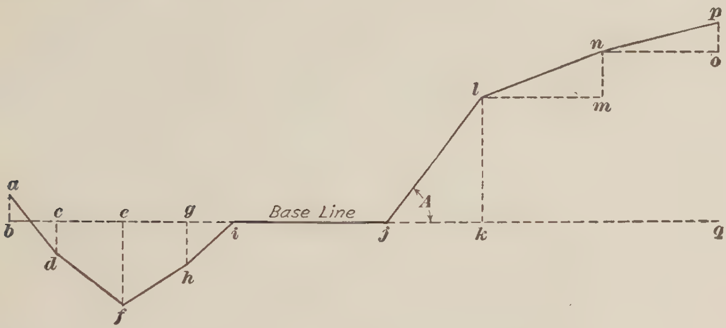


FIG. 5

situated too far away from the base line, as, for instance, points *n* and *p*, supplementary base lines *l m* and *n o* are drawn parallel to *i j*, on which lines the ordinates are erected, giving the points of intersection *n* and *p*.

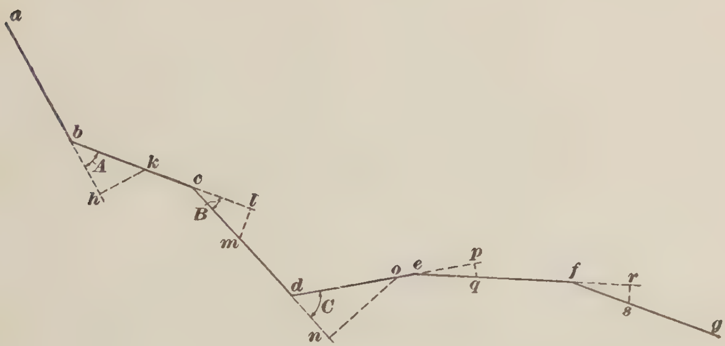


FIG. 6

The plotting should be done carefully, and as a check the angles between the tangents should be read with a protractor and the lengths of the tangents should be measured between the intersection points.

32. Another method which is practically as accurate as the coordinate method, and considerably more rapid, is the *tangent method*, illustrated in Fig. 6. In this method the lines are prolonged a definite amount beyond the points of intersection and the tangential offsets corresponding to the angles of intersection are plotted. For instance, if line $a\,b$ is produced beyond the point of intersection b, and a distance $b\,h$ equal to 200 feet is laid off on the prolongation, then the tangential offset $h\,k = 200 \times \tan\ A$. Let the offset $h\,k$ be plotted at h, then the line drawn from b to k gives the direction of the tangent $b\,c$; line $b\,k$ is therefore produced and on it is laid off the distance $b\,c$. Similarly, line $b\,c$ may now be prolonged for a distance of 200 feet to point l, at which point the offset $l\,m = 200 \times \tan\ B$ is plotted; the direction of the tangent $c\,d$ is obtained by joining the points c and m, and the length $c\,d$ is laid off on line $c\,m$ produced. In like manner may be plotted the offsets $n\,o$, $p\,q$, and $r\,s$, and the tangents $d\,e$, $e\,f$, and $f\,g$.

33. A very common method is to plot the transit line by means of a protractor and scale; but it is impossible to plot the line accurately by this method, no matter how finely graduated the protractor may be.

When the line has been correctly laid out by any of the preceding methods, the curves should be drawn in and the stations should then be marked off on the line and the survey plotted from the notes. Any of the conventional topographical signs may be adopted for the detailed topography. It is essential to have the names of all property owners written in on the plan.

34. Profile.—A ground and a grade profile are shown in Fig. 7, the ground profile being indicated by the curved, irregular line $a\,b\,c$ and the grade profile by the broken line $d\,e\,f\,g$. The profile may be plotted on the plan sheet and is generally placed below the plan and at the bottom of the sheet. The datum line is drawn and an elevation is assumed for it sufficiently low to allow the ground line to be plotted without any point falling below the datum line. Stations are marked off on this base line at distances apart corresponding with those

on the plan and perpendiculars are erected on which the elevations are laid off from these station points. But, since the profile represents the stations as if situated in one and the same vertical plane, while the plan shows the transit line as a combination of a number of straight lines and curves, it follows that a perpendicular projected from a station on the plan will not necessarily coincide with a perpendicular drawn from the same station on the profile. However, in studying the plan it will be found that there is some portion of the transit line where the stations in the plan and in the profile can be made to come perpendicularly over one another, if such arrangement is found more convenient. In that case the remaining portion of the profile is allowed to come as it will.

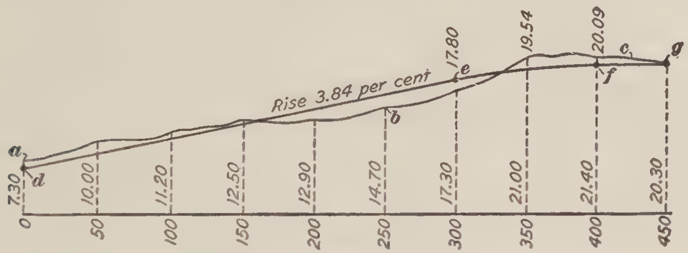


FIG. 7

35. The ground line of the profile should represent the profile of the original surface on the proposed center line of road. If the transit line corresponds with the proposed center line, the elevations taken on the transit line will be the ones used, otherwise the center-line elevations will have to be obtained from the cross-sections. The ground-line elevations are written and plotted on the verticals corresponding to their respective stations. The points thus obtained are connected by straight lines. Culverts, bridge openings, elevations of car rails adjacent to the improved surface, manholes, curbs, corner boards of houses, etc., should also be plotted on the profile so that all the information necessary for determining the grade will be at hand.

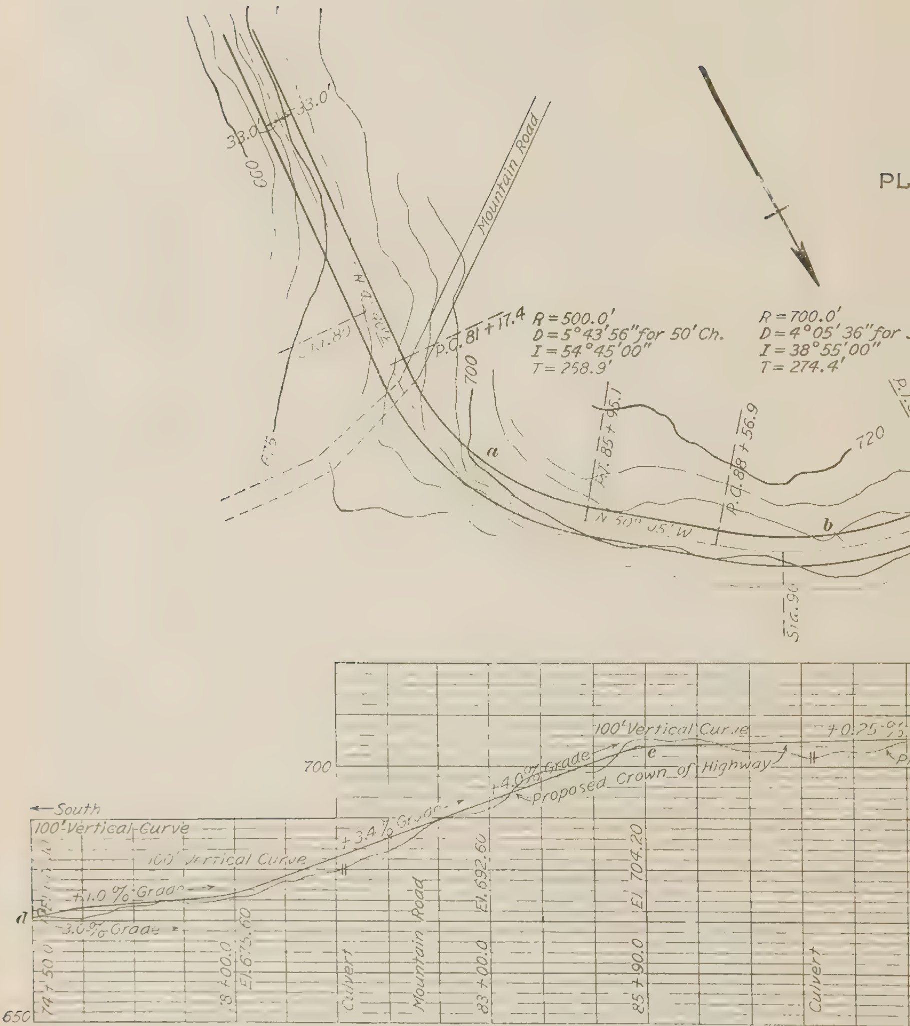
36. The same horizontal scale used for the plan is used in scaling off the stations of the profile, but the scale used in plotting the elevations is much greater. If the horizontal scale of

the plan is 40 feet to the inch, the vertical scale of the profile is generally taken as 8 feet to the inch; if the horizontal scale is 50 feet to the inch, the vertical scale is usually made 10 feet to the inch. It is advisable to ink in the ground line of the profile since in determining the grade line many erasures may be necessary before the final grade is adopted.

37. Cross-Sections.—The cross-sections should be plotted on cross-section paper. The scale used should be as much as $\frac{1}{4}$ inch to the foot, since the estimate of cut and fill is made from these cross-sections, and the use of a large scale makes the determination of areas more accurate.

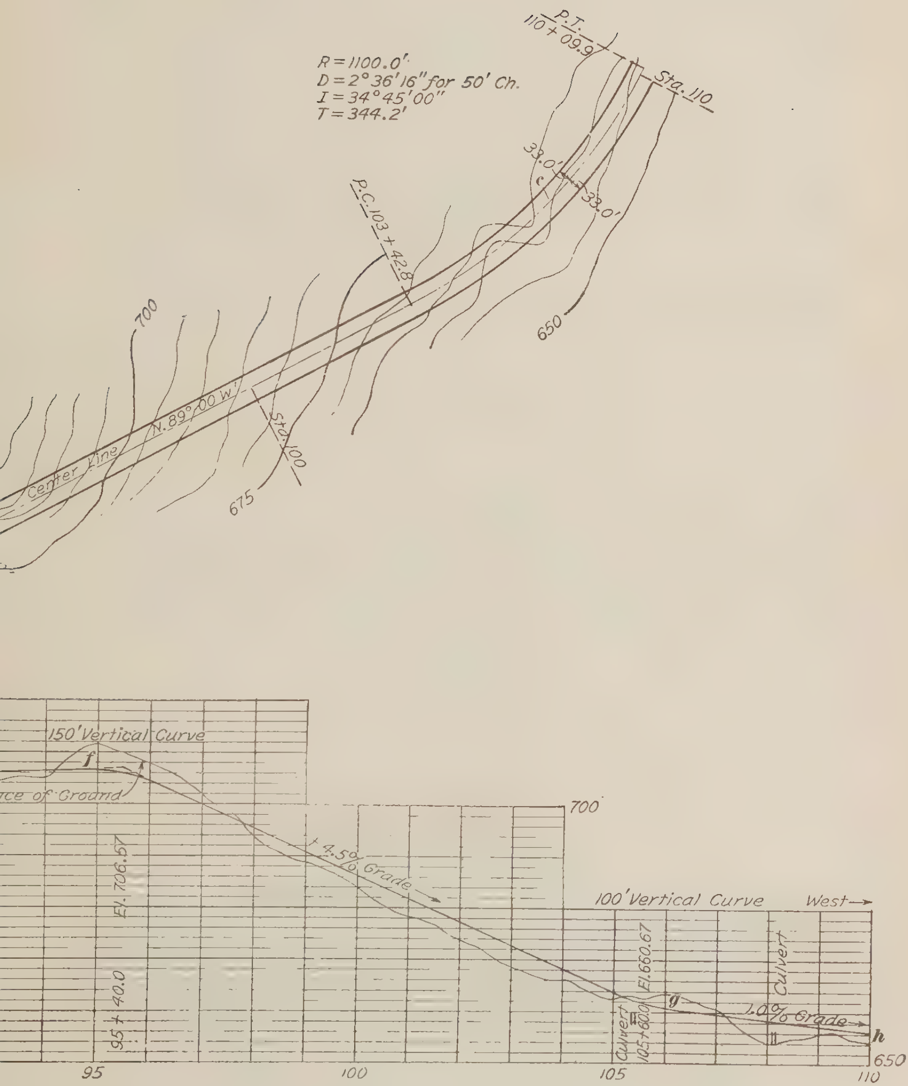
It is the custom of some engineering offices to furnish the men in the field with plans and cross-sections of the proposed road. In some of the larger states, where the engineering force is quite large and the drawings are made at a central office, it is essential for each engineer in charge to have a copy of the plans. This is most readily accomplished by making blueprints from the original drawings. The blueprints should be made on sheets of a standard and convenient size. When the drawing of the plan and profile is to be traced, the sheets of tracing paper can be cut to the desired size and as much of the drawing traced on each sheet as it will contain. The roll of thin paper on which the cross-sections have been plotted may be cut into sheets of a corresponding size for blueprinting. When the blueprints have been made, the whole set may be bound together. A convenient size of sheet is one measuring about 2 feet wide and 3 feet long. Each sheet should bear a title describing its contents.

38. Examples of Plans and Profiles.—In Fig. 8 are shown a plan and a profile of a new location of a highway made by the Board of Water Supply of New York City. The method employed in Fig. 8 for indicating elevations, distances, grades, and curvatures, has previously been explained, with the exception of the method for laying out a vertical curve, and hence a complete discussion of this subject is given in the following articles. It should be noted, however, that in the plan the abbreviations for *degree of curve* and *angle at center* are D and I,



PROFILE ON CENT

I L T 298, 317B § 22



P.T. 110 + 09.9
R = 1100.0'
D = 2°36'16" for 50' Ch.
I = 34°45'00"
T = 344.2'
Sta. 110
33.0'
c
33.0'
P.C. 103 + 42.8
650
700
N. 89° 00' W.
Center Line
Sta. 100
675
150' Vertical Curve
f
ace of Ground
700
El. 706.57
95 + 40.0
+ 4.5% Grade
100' Vertical Curve
West
El. 660.67
Culvert
105+60.0
g
Culvert
1.0% Grade
h
650
95
100
105
110

E

respectively. Also, that the length of chord is taken as 50 feet instead of 100 feet and, consequently, the usual formula for the degree of curve does not apply. The formula to be used in this case is derived as follows:

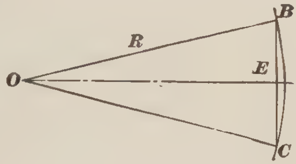


FIG. 9

Let BC, Fig. 9, be a chord of 50 feet subtending an arc described with a radius BO equals R from the center O. Then by definition the angle BOC equals D. Let OE be the bisector of the angle BOC; this line will also bisect the chord BC and be perpendicular to it. Then, in the right-angled triangle BEO,

$$BE = OB \times \sin BOE$$

or,

$$\frac{50}{2} = R \sin \frac{1}{2} D$$

whence,

$$\sin \frac{1}{2} D = \frac{25}{R}$$

The values for D, the degrees of curves at a, b, and c, Fig. 8, were determined by this formula. For example, for the curve at a, $R = 500$ feet. Therefore, by the formula,

$$\sin \frac{D}{2} = \frac{25}{500} = .05$$

whence,

$$\frac{D}{2} = 2° \ 51' \ 58''$$

and,

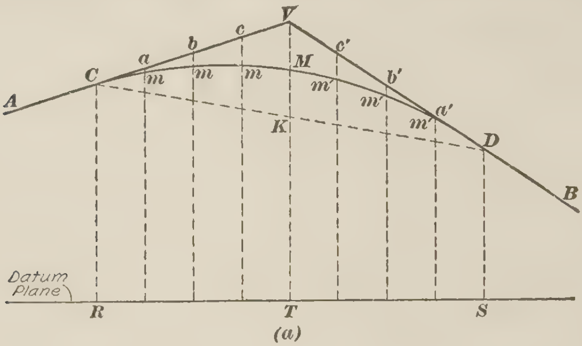
$$D = 5° \ 43' \ 56''$$

VERTICAL CURVES

39. A vertical parabolic curve is used at the intersection of two grades to avoid the sudden change of slope in passing from one grade to the other. If the angle formed by the intersection of the grade lines points upwards, it is called a peak; if it points downwards, it is called a sag.

40. Vertical Curve at a Peak.—If AV and BV, Fig. 10 (a), are two grade lines meeting at V, a vertical curve CMD must be introduced joining these lines. The horizontal projection of $CV = VD$ is always made a whole number of

stations; and the horizontal distances between C and a, a and b, b and c, etc., are equal and correspond to the station or half



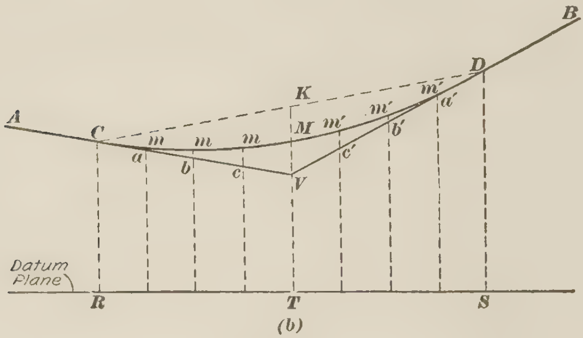


FIG. 10

station interval; point M is always midway between K and V so that $KM = MV$.

41. Let E be the elevation of C, Fig. 10 (a), E' that of D, and H that of V; that is, $E = RC$, $E' = SD$, and $H = VT$. Then for the elevation of K,

$$KT = \frac{1}{2}(RC + SD) = \frac{1}{2}(E + E')$$

and for that of M,

$$MT = \frac{1}{2}(VT + KT) = \frac{1}{2}\left(H + \frac{E + E'}{2}\right)$$

Subtracting the elevation of M from that of V, the remainder will be the distance VM from the vertex to the vertical curve and is called the correction in grade at the point V;

$$V\,M = H - \frac{1}{2}\left(H + \frac{E+E'}{2}\right) = \frac{1}{2}\left(H - \frac{E+E'}{2}\right) \qquad (1)$$

It is a property of the parabola that the correction in grade $a\,m$ at any point a is given by the equation,

$$a\,m = V\,M \times \left(\frac{C\,a}{C\,V}\right)^2 \qquad (2)$$

The corrections in grade at points a', b', and c' along $D\,V$ are equal to those for a, b, and c, since $C\,a = D\,a'$, $a\,b = a'b'$, etc.

EXAMPLE.—A plus .4 per cent. grade meets a minus .5 per cent. grade at Sta. 190, the elevation of which is 161.3 feet. If a vertical curve 400 feet long is inserted, what is the correction in grade and the corresponding grade elevation at each station and half station?

SOLUTION.—In this example, $V\,C = V\,D = 200$ ft.
Elevation of C is $161.3 - 2 \times .4 = 160.5$ ft. $= E$.
Elevation of D is $161.3 - 2 \times .5 = 160.3$ ft. $= E'$.

Elevation of K is $\frac{1}{2}(E+E') = \frac{1}{2}(160.5 + 160.3) = 160.4$ ft.
Elevation of V is $H = 161.3$ ft.
These values being substituted in formula **1**,

$$V\,M = \frac{1}{2}(161.3 - 160.4) = .45 \text{ ft.}$$

Since, for the second stake, $C\,a = 50$ ft. and $C\,V = 200$ ft., formula **2** gives

$$a\,m = V\,M \times \left(\frac{50}{200}\right)^2 = .45 \times \frac{1}{16} = .03 \text{ ft.} = a'\,m'$$

Similarly,
$$b\,m = V\,M \times \left(\frac{100}{200}\right)^2 = .45 \times \frac{1}{4} = .11 \text{ ft.} = b'\,m'$$

$$c\,m = V\,M \times \left(\frac{150}{200}\right)^2 = .45 \times \frac{9}{16} = .25 \text{ ft.} = c'\,m'$$

The original and corrected grade elevations are as follows:

STATION	ORIGINAL ELEVATION		CORRECTION		CORRECTED ELEVATION
188, or C	160.50	–	.00	=	160.50
+50	160.70	–	.03	=	160.67
189	160.90	–	.11	=	160.79
+50	161.10	–	.25	=	160.85
190	161.30	–	.45	=	160.85
+50	161.05	–	.25	=	160.80
191	160.80	–	.11	=	160.69
+50	160.55	–	.03	=	160.52
192, or D	160.30	–	.00	=	160.30

42. Vertical Curve at a Sag.—In Fig. 10 (*b*), two grade lines, AV and VB, meet so as to form a sag. Using the notation of the preceding article, the elevation of K will be $TK = \frac{1}{2}(E+E')$, as before, and the elevation of M will be $TM = \frac{1}{2}\left(H + \frac{E+E'}{2}\right)$. But in this case M is above V, and therefore, the correction VM in grade will equal $TM - TV$; that is,

$$VM = \frac{1}{2}\left(H - \frac{E+E'}{2}\right) - H = \frac{1}{2}\left(\frac{E'+E}{2} - H\right) \qquad (1)$$

The correction in grade at any point a will be given by formula **2**, Art. **41**, as before, but this correction is now to be added to the old grade at a to obtain the corrected elevation.

EXAMPLE.—The grade of CV, Fig. 10 (*b*), is -1.2 per cent.; that of VD is $+.8$ per cent., and the elevation of V is $+49.2$ feet. Find the corrections in grade and the corrected elevations at stakes 100 feet apart, if the length of the vertical curve is 800 feet.

SOLUTION.—The uncorrected grade elevations are as follows:

ALONG CV

At first stake C	$49.2 + (4 \times 1.2) = 54.0$
At second stake a	$49.2 + (3 \times 1.2) = 52.8$
At third stake b	$49.2 + (2 \times 1.2) = 51.6$
At fourth stake c	$49.2 + \quad 1.2 \quad = 50.4$
At fifth stake V	$49.2 + \quad 0 \quad = 49.2$

ALONG VD

At sixth stake c'	$49.2 + \quad .8 \quad = 50.0$
At seventh stake b'	$49.2 + (2 \times .8) = 50.8$
At eighth stake a'	$49.2 + (3 \times .8) = 51.6$
At ninth stake D	$49.2 + (4 \times .8) = 52.4$

Therefore, $\frac{1}{2}(E+E') = \frac{1}{2}(54.0+52.4) = 53.2$

And, by the formula of this article,

$$VM = \frac{1}{2}(53.2 - 49.2) = 2.0 \text{ ft.}$$

Formula **2**, Art. **41**, may now be applied.

Corrections in grade at the second and eighth stakes are

$$2 \times \left(\frac{100}{400}\right)^2 = 2 \times \frac{1}{16} = .13$$

Corrections at the third and seventh stakes are

$$2 \times \left(\frac{200}{400}\right)^2 = 2 \times \frac{1}{4} = .50$$

Corrections at the fourth and sixth stakes are

$$2 \times \left(\frac{300}{400}\right)^2 = 2 \times \frac{9}{16} = 1.13$$

The corrected elevations will be

Station	Original Elevation		Correction		Corrected Elevation
At first stake C	54.0	+	.00	=	54.00
At second stake	52.8	+	.13	=	52.93
At third stake	51.6	+	.50	=	52.10
At fourth stake	50.4	+	1.13	=	51.53
At fifth stake	49.2	+	2.00	=	51.20
At sixth stake	50.0	+	1.13	=	51.13
At seventh stake	50.8	+	.50	=	51.30
At eighth stake	51.6	+	.13	=	51.73
At ninth stake D	52.4	+	.00	=	52.40

EXAMPLES FOR PRACTICE

1. Find the corrections in grade and the corrected elevations at stakes 50 feet apart, if the vertical curve is 400 feet long: grade of $CV = +.4$ per cent.; of $VD = -.6$ per cent.; elevation of $V = 101.4$ feet.

Ans. Corrections in grade: .00, .03, .13, .28, .50, .28, .13, .03, and .00
Corrected elevations: 100.60, 100.77, 100.87, 100.92, 100.90, 100.82, 100.67, 100.47, and 100.20

2. Find the corrections in grade and the corrected elevations at stakes 100 feet apart if the vertical curve is 600 feet long. Grade of $CV = -1.6$ per cent.; of $VD = +.2$ per cent.; elevation of $V = 128.66$ feet.

Ans. Corrections in grade: .00, .15, .60, 1.35, .60, .15, and .00
Corrected elevations: 133.46, 132.01, 130.86, 130.01, 129.46, 129.21, and 129.26

DESIGN OF HIGHWAY SYSTEMS

STATE, MUNICIPAL, AND PARK HIGHWAY SYSTEMS

CLASSIFICATION

43. Principal Road Systems.—The several classes of highway systems may be divided into the following classes: National, state, county, town, city, park, and estate systems. Of these the national, county, and town highway systems are governed by the same general principles as those applying to the state highway systems, and as estate highway systems are very similar to those of parks, it follows that a consideration of state, city, and park highway systems will cover all cases.

STATE HIGHWAY SYSTEMS

44. Preparatory Work.—The design of a system of state trunk highways is simplified if a comprehensive topographical map of the state is at hand, such as is made by the United States Coast and Geodetic Survey. If such maps are not obtainable, a map showing simply the roads in plan can be used, but with the latter the study cannot be made in so satisfactory a manner except by doing a great deal of reconnaissance work. The interstate and intrastate trunk lines, the interurban trunk lines, and popular routes of travel should first be laid out. Information should be obtained from the officials in the adjoining states relative to the main roads in those states, so that the systems in the two states may be connected. The intrastate highways can next be added to the system. These highways pass through towns and connect towns situated within a few miles of each other. Finally, to the system of trunk highways,

there should be added the feeders which will develop the commercial, industrial, and agricultural resources of every part of the state. Before deciding to include any section of road in the system, a general idea should be obtained as to the practicability of its construction at a reasonable cost, and it should be ascertained whether the road is the best one to be built from the standpoint of the welfare and development of the communities through which it passes.

MUNICIPAL HIGHWAY SYSTEMS

45. Fundamental Requirements.—A street plan is not well designed unless it gives consideration to the topography and the question of drainage. Topographical conditions will sometimes preclude the use of a uniform rectangular system if easy grades are required. The history of the growth and development of large cities should be carefully studied, since it is only from these examples that it is possible to predict the requirements that have to be met, as a result of changed conditions. What is at the present time a suburb may in a few years become an important part of the city, and the street plan should, therefore, be designed on such comprehensive lines that provision is made for growth.

46. Rectangular Street Plan.—The rectangular block system has been used in many cities where topographical conditions would permit. Such a system, however, should contain diagonal streets radiating from the city center to large public squares, and from thence to the outskirts, thus allowing the traffic to move from one part of the city to another with the greatest despatch.

47. Circumferential Street Plan.—The systems of many European cities, which are pointed to as examples of comprehensive street plans, not only have a rectangular plan intercepted by diagonal streets, but they also have so-called circumferential streets that roughly encircle the city. This is well illustrated by the street plans of such cities as Paris, Berlin, Vienna, and Moscow.

PARK HIGHWAY SYSTEMS

48. Conditions Affecting Possible Design.—An ideal park system for any city or community would be one in which all of the spaces reserved for parks are connected with scenic boulevards. Many of the parks will be found on the outskirts of the larger cities, since places that still retain their natural beauty can be acquired only in such localities. The different parks may be connected by boulevards and drives, which, if designed in the proper manner and with proper esthetic effect, become a part of the parks themselves. The design of the highways of the system is not difficult. Distance, alinement, and grade are not of so much importance as in the case of a highway carrying both pleasure and commercial traffic. Particular emphasis should be given to the esthetic possibilities of the highways. This may sometimes involve entirely new layouts, such as roads along the banks of a river, the seashore, or across some area the natural environment of which is especially beautiful.

DESIGN OF INDIVIDUAL HIGHWAYS

LOCATIONS, GRADES, CURVES, WIDTHS, AND CROSS-SECTIONS

49. Scope of Design.—A complete design of an individual highway comprises the consideration of the following factors: Location, grade, alinement, width, crown, drainage, foundation, type of roadway surface, and estimate of cost. The four last-mentioned subjects will be treated in another Section.

LOCATION

50. Controlling Factors.—In connection with the location of new highways or the relocation of old highways, careful consideration should be given to the following factors: (1) The highway should develop to a maximum extent the commercial,

agricultural, and industrial interests of the community. (2) The highway should serve the largest possible number of people. (3) The amount of cut and fill should be reduced to a minimum. (4) Good natural drainage should be secured and longitudinal surface drainage obtained by establishing a minimum grade of .5 per cent. (5) Other conditions permitting, natural, stable foundations should be utilized. Such natural foundations as low swampy ground, locations subject to overflow or where the conditions are such that there is a tendency of one stratum of soil to slide or slip upon another should be avoided. (6) Grades should be as low as practicable, as the maximum grade limits the amount of the load that can be moved over a highway. (7) Locations encircling hills should be used rather than steep inclines over summits. (8) If the topography is such that there is a continual rise, the grade line should have no descending grades. (9) Curves should be long and easy and sharp curves avoided. (10) In mountainous regions, highways should be built on side slopes and, if practicable, northern exposures and locations near stream beds should be avoided. (11) Dangerous railroad crossings should be avoided.

51. When a new highway is in a stage of development, no expensive improvements, such as grading, drainage, foundations, pavement, and bridges should stand as obstacles to the proposed abandonment of a poor location. Furthermore, a suitable width and right of way on a relocation may usually be secured at a reasonable expense. Methods of securing rights of way vary in the several states. Some states have laws that permit highways to be located and constructed before landowners are paid for the rights of way. If dissatisfied with the final award of the highway authorities, the owners may appeal to the proper court. This procedure is based on the principle that the expeditious construction of a highway in a desirable location is advantageous to the people as a whole. As a general proposition, the land is acquired economically under this method. In states where the right of way must be paid for before the highway is constructed, the prices demanded by owners are in many cases exorbitant, and, in addition, the overhead charges

are frequently very large, as expensive legal and engineering work is often required before adjustments are completed.

52. Preliminary Selection of Route.—With the aid of a contour map made from the data obtained in the preliminary surveys, the final route may be approximately laid down on the map. In doing this, certain principles should be observed as far as practicable. The terminals and intermediate points that must be reached, sometimes called ruling points, should be connected by the shortest and most direct route consistent with economy and easy grades. Directness may have to be sacrificed and length increased in order to secure easy grades. It is generally better to curve around a very steep hill than to go straight over it. A judiciously located route around the hill will not be materially longer than a direct route over the hill, for the reason that both lines are curved; the line over the hill is curved in a vertical plane, while the circuitous line around the hill is curved in a horizontal plane. For example, if a circular hill has slopes of 50° 26′ on both sides, the distance around it on a level is no longer than the line over it, and by going around it, the waste of tractive power required to raise the load over it is avoided. The total length of a circuitous route will often exceed that of a direct line, but, if the grades of the longer route are less than those of the shorter, the loss through increase of distance may be compensated by the gain in speed and the heavier loads permitted by the easier grades.

53. Deep valleys should be crossed at as high an elevation as practicable. A narrow part should be selected, and, if a bridge is required, the crossing should be at right angles. All obstacles where structures are necessary should be crossed as nearly as possible at right angles. The cost of skew structures increases nearly as the square of the secant of the angle between the center line of the structure and the line at right angles to the valley.

When the line runs along the side of a valley, the obstacles that it has to cross are chiefly the small branch valleys running into the main valley, and the promontories or ridges that

separate and form the small valleys. Under these circumstances, the greatest economy will generally be attained by curving around the promontories in a serpentine course. In some cases, it may be cheaper to make a straight crossing and avoid the detour; this can only be determined for each particular case by comparing the cost of construction with the cost of operation and maintenance.

When a river has to be crossed, the point of crossing is a ruling point, and the line of the road must be made subordinate to it. Careful study should be given to selecting the best site for the bridge. The conditions that govern the selection of the site are: (1) A good foundation for the abutments and piers; and (2) stability of the banks, to insure the permanent concentration of the waters in the same channel. The approaches to the bridge should be free from sharp curves and steep inclines, and the axis of the bridge should, if possible, be placed at right angles to the direction of the current.

54. Roads placed in the lowest parts of valleys are subject to flooding, while those on the side of a hill, where the strata are inclined toward the valley, or the slopes are composed of loose material or permeable rock with seams of clay, are liable to slips and washouts caused by the action of frost or heavy rainfalls.

In placing the line on a hillside, the direction of the inclination of the strata should be observed, and the line located so that the tendency of any movement of the strata will be into the hill rather than down the side. For instance, in Fig. 11, a road located at *a* will be exposed to the accidents of landslides, which will be a source of continual trouble and expense, while the road located at *b* will be free from danger. In very deep excavations having long slopes, the slope is cut in benches, as shown at *a*, Fig. 12, in order to prevent water from acquiring a high velocity. The benches may be placed about 5 feet apart, and have a width of 1 to 5 feet. The surface of the benches should be sloped inwards to intercept material that may slip, and to check the velocity of the rainwater flowing down the slope.

This class of work involves increased expense in construction, which should be taken into consideration when weighing the advantages and disadvantages of different routes.

55. Deep cuttings should be avoided, unless the gain is so clear and substantial as to justify the greater cost of con-

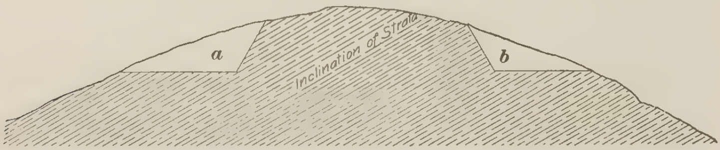


Fig. 11

struction and maintenance. Cuttings at high elevations are exceedingly objectionable, both on account of the difficulty in keeping the slopes in repair and of the danger of snow drifts. In a choice between a shallow cut and a low embankment, the embankment is to be preferred, for the reasons that the drainage can be made more effective and that there will be less trouble in keeping the road open in time of snow. In locations subject to heavy snowfalls, the road should, if possible, be located on the slopes facing south and east, as in these directions the power of the sun to melt snow is greatest.

56. For the purpose of avoiding accidents, railroads should be crossed either over grade or under grade. This rule has not been observed in the past, except on a few heavy-traffic roads

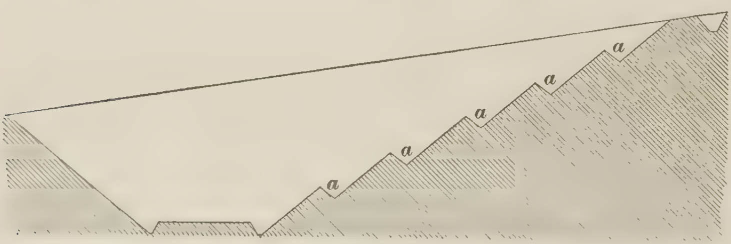


Fig. 12

in the vicinity of cities; but it is a rule that should be followed wherever possible, for grade crossings mean danger to every user of the highway.

If the course of the road is transverse to the direction of streams, it will have steep ascents and descents, and be exceedingly expensive to construct and maintain. Roads that run along the immediate bank of a river must of necessity intersect all the tributaries joining the river on that bank, thereby demanding a corresponding number of bridges, which are expensive to build and maintain.

57. Particular efforts should be made: (1) To cross ridges through the lowest pass; (2) to establish the grade line with reference to the natural surface so that it will lie above the highest water level of the side ditches; (3) to establish the grade line so that the cuts and fills will be equalized as nearly as possible; (4) to adjust the route so that it will follow the division line of properties as nearly as possible, provided that such adjustment does not materially affect the grade and cost of construction and maintenance.

58. Factors Determining the Final Selection of Routes.—A comparison of the merits and defects of several possible routes may be made by means of their respective profiles. The length, grades, rise and fall, character of the soil, and, to some extent, the opportunity for thorough drainage will be shown for each route by an inspection of its profile, from which the approximate cost of construction may also be estimated.

59. In comparing the gradients of routes, the rates of grade should be compared with special reference to the rates of the maximum grades on the different routes, as these grades will greatly affect the size of the loads that can be hauled over the roads.

In the comparison of the lengths of the routes, the increase in length due to *ineffective rise* and *excessive fall* should be taken into consideration. By **ineffective rise** is meant that rise in the grade that is not due to the difference of elevation between the two ends of the route; it is the actual rise in the grade line encountered in passing from the higher end of the route to the lower end. By **excessive fall** is meant that fall

in grade that is in excess of certain specified rates of grade encountered in passing from the higher end of the route to the lower end. These specified rates of grade vary with the nature of the roads. Thus, should the fall in grade on an earth road exceed 9 per cent., on a gravel road 6.5 per cent., or on a macadam road 3 per cent., any fall in excess of the percentage for that particular kind of road will be considered excessive fall.

The percentages mentioned are about the average rates of grade that constitute the angle of repose for vehicles for the three kinds of roadways named. The term *angle of repose*, as here used, means the grade on which a vehicle by its own weight will maintain a uniform speed without the application of additional power. On descending grades steeper than these, a holding-back force must necessarily be applied to the loads. Ineffective rise and excessive fall are both counted in a direction passing from the *higher* to the *lower* end of the line.

60. The length of the route, taken in connection with the ineffective rise and excessive fall, is called its **resisting length.** The resisting lengths of different routes may be compared by referring them to the work required to move a given load along them. If c is the coefficient of friction, the work U performed in hauling a weight W along a horizontal distance h is given by the formula

$$U = Wch \qquad (1)$$

If, however, in the distance h there occurs a rise (or excessive fall) r, the work U' necessary to haul the weight along the inclined path is

$$U' = Wch + Wr \qquad (2)$$

In order to reduce this to an equivalent level grade, U' must be given a form similar to that of U. Letting $r = ch'$, where $h' = \frac{r}{c}$, the value of U' becomes

$$U' = Wch + Wch' = Wc(h + h') \qquad (3)$$

This formula shows that the inclined path is equivalent to the corresponding horizontal path increased by the quantity h', or $\frac{r}{c}$.

In general, if l is the length of a route, and l_0 is the equivalent length of a route having, with respect to the former, a sum of excessive falls and ineffective rises equal to r, the value of l_0 is

$$l_0 = l + kr \tag{4}$$

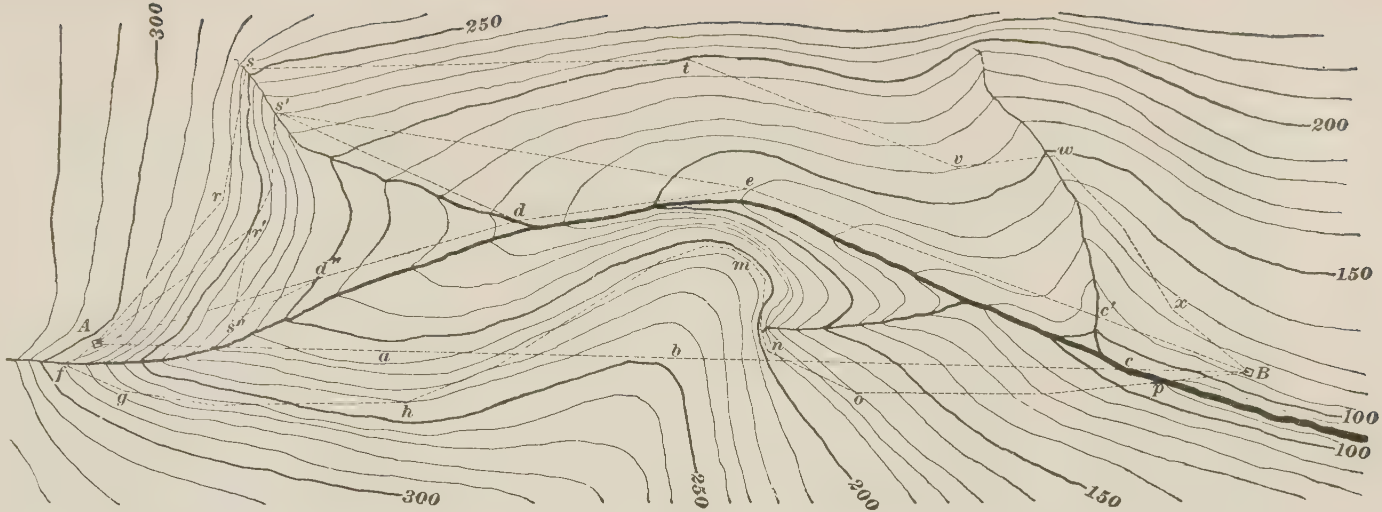
where $k = \frac{1}{c}$, and may have the following* average rough values: for earth roads, $k=12$; for gravel roads, $k=20$; and for macadam roads, $k=33$.

By comparing the resisting lengths obtained by applying this formula to the grade lines of the different routes, a reasonably accurate comparison may be made between the routes in regard to what may be considered the comparative resistances that they oppose to traffic by reason of actual length, ineffective rise, and excessive fall.

61. Some comparison of the character of the soils along the different routes, with reference to their adaptability to the purposes of road building, may be obtained from the notes usually given on the profile. For each route, the opportunity for thorough drainage can be judged largely from the profile. The amount of grading, as estimated for each line from its profile, taken in connection with the amount of bridging and the number of culverts required, as shown on the profile, will serve as a basis for estimating the relative costs of the different lines.

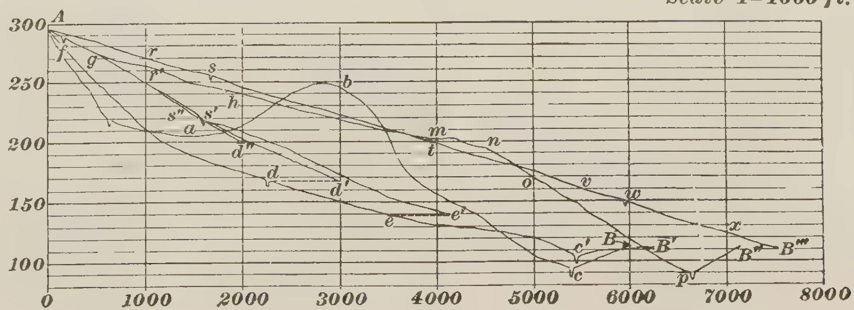
62. A comparison of the convenience to traffic can be made by examining the routes on the ground or on a very complete map. The road should, as far as practicable, be so located as to be the most convenient for the greatest portion of its traffic. The position of a road that will best accommodate its traffic will generally be that in which, all other conditions being equal, the sum of the distances through which each ton of freight is moved and each passenger travels will be a minimum; in other words, it will be that position which will

* These average values may be used for ordinary roads and rough estimates. The actual values will generally vary from about 7 to 22 for earth roads, 15 to 30 for gravel roads, and 30 to 40 for macadam roads, according to the condition of the roadway surface. Additional data on this subject are found in another Section.



(a)

Scale 1" = 1000 ft.



(b)

FIG. 13

require the mass of the traffic to be moved the least distance in reaching its destination. Some consideration should also be given to the question of whether a road will be pleasant for those who are to travel on it. In the case of pleasure drives, this is an important condition.

63. Example of Road Location.—As an illustration of road location, let it be assumed that it is desired to locate and construct a highway between the points A and B, Fig. 13 (a), which are 6,000 feet, or slightly more than $1\frac{1}{8}$ miles, apart, measured in a direct line. The topographical features of the country are shown in the figure, the relative elevations being shown by contour lines. It will be assumed that the road is to be constructed to sustain a very heavy traffic between the points A and B, and that it is not essential for it to pass through any intermediate points, though rather desirable that it should pass through or near the points d and e in the valley, provided that such location will not be disadvantageous in other respects. As the road is one of considerable importance, several routes are surveyed, in order to determine the best route. The profiles of the different routes are shown below the map in Fig. 13 (b). Only the surface lines are shown in these profiles. In order to avoid confusion in comparing the different profiles, the grade lines have been omitted; they may be considered to have approximately the same positions as the surface lines and to be somewhat more uniform.

64. The direct route $A\ a\ b\ c\ B$, Fig. 13 (a), is the shortest as regards horizontal distance, being just 6,000 feet long, horizontally. But the profile shows that, in passing from the higher terminus A to the lower one B, a rise of about 43 feet is encountered between a and b, and another rise of about 19 feet occurs between c and B, making a total ineffective rise on this route of $43+19=62$ feet. Between the end A of the line and the first crossing of the stream, which is a distance of 625 feet, the fall is about 75 feet, or at the rate of $\frac{75\times 100}{625}=12$ per cent.

Assuming that the road is to be an ordinary earth road, that part of the fall in excess of 9 per cent. should be treated as a like

amount of rise, according to Art. **59**. A fall of 9 per cent. for a distance of 625 feet makes a total fall of $9\times6.25=56.25$ feet, leaving an excess of $75-56.25=18.75$ feet. Also, in the 400 feet of horizontal distance, situated between points distant 350 and 750 feet, respectively, beyond b, the fall is about 50 feet, or at the rate of

$$\frac{50\times100}{400}=12.5 \text{ per cent.}$$

The latter value is an excess of $12.5-9=3.5$ per cent., or a total excess of $4\times3.5=14$ feet. By applying formula **4** of Art. **60**, the length of route, l_0, to be assumed in making the comparison is

$$6{,}000+12\times(62+18.75+14)=7{,}137 \text{ feet}$$

This route involves very steep grades, the maximum in one direction being not less than 12 per cent., and in the opposite direction about 5 per cent.

65. The route $A\,d\,e\,B$, Fig. 13 (a), following the general course of the stream, would usually be the first route to be tried, especially if the surveys were made from the lower terminus B toward the upper terminus A, as will most commonly be the case. The surface line $A\ d\ e\ B'$, the profile of the route, is shown in (b). This profile shows that the route is a favorable one having only the very small amount of ineffective rise that occurs between c' and B; the length of this route is 6,250 feet. In the first 1,000 feet from A, however, the route has a fall of about 85 feet, requiring a grade of 8.5 per cent., which is steeper than is desirable for the character of the traffic that the road is to sustain.

In the attempt to avoid this steep grade, the lines $A\ r'\ s'\ d$ and $A\ r'\ s'\ e$ are run as alternative lines for a part of this route. The profiles of these lines are shown in (b) by the surface lines $A\ r'\ s'\ d'$ and $A\ r'\ s'\ e'$, respectively. The line $A\ r'\ s'\ d$ increases the length of the route by the amount $d\,d'$ shown in (b), or about 700 feet, and the line $A\ r'\ s'\ e$ increases it by the amount $e\,e'$, or about 600 feet. Hence, the total horizontal length of the line $A\ s'\ d\ B$ will be $6{,}250+700=6{,}950$ feet, and the total horizontal length of the line $A\ s'\ e\ B$ will be $6{,}250+600=$

6,850 feet. To avoid crossing the stream at s' the line $A\ r'\ s''\ d''$ is tried as an alternative for part of the route.

There is no excessive fall in the line $A\ s'\ d\ B$, but between the points c' and B there is about 8 feet of ineffective rise, giving a theoretical increase of $8 \times 12 = 96$ feet in the length of the line. For the purposes of comparison, therefore, the value l_0 for the line $A\ s'\ d\ B$ is $6{,}950 + 96 = 7{,}046$ feet, and for the line $A\ s'\ e\ B$ it is $6{,}850 + 96 = 6{,}946$ feet. For both these lines, the maximum grade, which occurs between r' and s', is 5 per cent.

66. The route $A\ f\ g\ h\ m\ n\ o\ p\ B$, Fig. 13($a$), is surveyed at a higher elevation along the opposite side of the valley. This line is a modification of the direct line $A\ b\ c\ B$; it is very crooked, however, and its length, horizontally, is about 7,060 feet. For this route, the surface line $A\ h\ n\ B''$ is the profile. Its maximum grade, which is between n and p, is 5 per cent. Between the point p and the terminus B, there is about 12 feet of ineffective rise, making the value of l_0 for this route equal to

$$7{,}060 + 12 \times 12 = 7{,}204 \text{ feet}$$

67. As the traffic on the road is to be of a very heavy character, making easy grades a very important consideration, still another line is surveyed, for the purpose of ascertaining whether a line having easy grades can be obtained. This line is located very carefully, with the object of obtaining, if possible, a line having no grade steeper than 2.5 per cent. Such a line is $A\,r\,s\,t\,v\,w\,x\,B$, Fig. 13 (a), which has a length of about 7,550 feet. There is no ineffective rise or excessive fall on this line. The surface line $A\ r\ s\ t\ v\ w\ x\ B'''$ is the profile of this line. The greater part of the line approximates a uniform grade of 2.4 per cent., and the maximum grade need not be greater than 2.5 per cent.

68. In order to afford a ready comparison between the different lines surveyed, the values that have been determined are assembled in Table II. For convenience of reference, the different lines are numbered.

TABLE II

LENGTHS AND MAXIMUM GRADES OF ROUTES, FIG. 13

Number of Route	Line	Actual Length l Feet	Resisting Length l_o Feet	Maximum Grade Per Cent.
1	$A\ b\ c\ B$	6,000	7,137	12.0
2	$A\ d\ e\ B$	6,250	6,250	8.5
3	$A\ s'\ d\ B$	6,950	7,046	5.0
4	$A\ s'\ e\ B$	6,850	6,946	5.0
5	$A\ m\ o\ B$	7,060	7,204	5.0
6	$A\ s\ w\ B$	7,550	7,550	2.5

This tabulation of values, together with the map and profiles of the routes, will allow an intelligent selection of the route to be made. From the values of l_0 and of the maximum grade, it is seen that routes Nos. 2, 4, and 6 are the most favorable ones. Route No. 2, or the direct route through the valley, is a thoroughly practical route, provided that the maximum grade of 8.5 per cent., extending for a distance of 1,000 feet, is not objectionable. This route gives the smallest value of l_0. Route No. 4 is a modification of route No. 2; it reduces the maximum grade to 5 per cent., and increases the length of the line nearly 700 feet. Route No. 6 follows the brow of the hill on the left side of the valley. This is the longest of the routes surveyed, but it obtains the very easy maximum grade of 2.5 per cent., and, as it has no ineffective rise or excessive fall, it gives a value of l_0 equal to l, the actual length of the line. This is by far the best route for heavy traffic, and for a mixed traffic it will generally be the most satisfactory. If it is necessary to pass through the points d and e, and, at the same time, have no steeper grade than 5 per cent., route No. 3 will fulfil the conditions. But, if there is no reason why the road should pass through the point d, route No. 4, which is a little shorter, is preferable.

ROAD GRADES

69. Maximum Grades.—The maximum grade may be governed by the loads to be hauled over a given highway. As economic transportation of commodities and passengers is affected materially by the grades on roads, it is especially important to keep the grades as low as practicable on important transportation routes. In many localities a maximum rate of grade is established, which is never exceeded except when the environments and the consideration of cost make it advisable to use a steeper grade. The grade must be established so as not to cause damage to the adjoining property and so as best to accommodate intersecting roads. Proper drainage and foundations should receive consideration in grade design. It is frequently necessary to raise the existing grade in order to obtain a satisfactory foundation. A saving may be effected by taking advantage of an old surface as a foundation, the new grade being established so as to disturb the old roadway as little as possible.

70. Balancing Cuts and Fills.—In establishing the grade of a road, attention should be given to the equalizing, as nearly as possible, of the excavations and embankments, so that the material excavated will be just sufficient to form the embankment. When this equalizing is not possible, the excavated material is either placed along the sides of embankments, or placed in banks, termed *spoil banks*, located at convenient points. When the material from the excavations is insufficient or unsuitable to form the embankments, the deficiency is made up from *borrow pits*, which are excavations made for the purpose of obtaining material. Although it is of material advantage to obtain a grade that will make the cuts and fills balance, it is obvious that often other considerations, such as avoidin damage to property or the disturbance of an old roadbed, are of far greater importance. The advisability of balancing cuts and fills from the standpoint of the cost of grading can be ascertained only by comparing the cost of hauling, in moving the earth from one point on the road to another, with the cost

of using a borrow pit at some nearer point. On hillside roads with moderate slopes, the center line of the road is so located that the excavation from the uphill slope will form the embankment on the downhill slope. On steep slopes, it may be necessary, in order to secure stability, to make the road entirely in excavation.

The amount of excavation and embankment is expressed in cubic yards, and the contractors that perform the work are paid a certain price per cubic yard of material excavated, the price depending on the kind of material. The volume of excavation is computed from the cross-sections obtained at the time of staking out the work, by using either the prismoidal formula or the method of average end areas.

71. Side Slopes.—In the making of excavations and embankments, a certain inclination must be given the side slopes to prevent slipping. This inclination is fixed by the character and condition of the material and the atmospheric influences of the locality. The slope should never be greater than the angle of repose of the material. This angle is about 37° for sand and loam, and 45° for loose rock. These angles correspond, respectively, to slopes of about 1.5 horizontal to 1 vertical, and 1 to 1. Solid rock will stand with vertical sides, but it is customary to give the sides a slope of about $\frac{1}{4}$ horizontal to 1 vertical.

STREET GRADES

72. Determining Factors.—It is usually difficult to decide properly all the various factors that must be considered in fixing the grades for a system of streets and adjusting them so as to harmonize at intersections. The three main objects to be attained are: first, the prompt removal of the surface water; second, the easiest gradients; and, third, the good appearance of the street.

73. Removal of Surface Water.—In order that the surface water may be promptly and effectually removed from a roadway, the rate of grade for the street should never be less

than one-fourth of 1 per cent., that is, .25 foot, or 3 inches, per 100 feet; the grade should not be as flat as this except in extreme cases and with first-class pavements, such as brick or asphalt. A minimum grade of one-half of 1 per cent. is as flat as should generally be used, and a grade as steep as 1 per cent. is very desirable. Where the grade line has the same elevation at the intersecting streets at both ends of a block, instead of making the grade level between those streets, it should be elevated in the center of the block sufficiently to cause the water to flow in each direction toward the intersecting streets.

74. Easiest Obtainable Gradients.—The selection of gradients for a street will be governed largely by the character and slope of the natural surface and by the nature and extent of the improvements that have been made along the street. Where no improvements have been made, deep cuts and fills are permissible in order to obtain favorable grades. But where buildings have been erected and improvements of a permanent nature have been made along a street before the grade is established, as is frequently the case, due regard must be given to such improvements in fixing the grade. The engineer must study the actual conditions as he finds them, and work out the most favorable grade possible under those conditions. This will seldom be as satisfactory a grade as could have been established before the improvements were made, but it should be as free from abrupt changes as possible and should approach as near to a uniform grade between street intersections as conditions will permit, thus giving the easiest obtainable gradients. It is very important that the grade of a street be established as soon as possible after the street is laid out and before improvements are made; the improvements should then conform to the established grade.

75. Good Appearance of Street.—Although the matter of appearance has been placed last, it is by no means the least in importance. The general appearance of a street greatly affects the value of the adjacent property; it is, consequently, of great importance that the grade of a street be such as to give it a good appearance. Where possible, the grade of the

street and the curb line should extend unbroken through each block from curb angle to curb angle. When it is necessary to change the grade at some point along the block, the change should be made at a property line and should be as small in amount as possible. Where the necessary change in the grade is considerable, the total change should be accomplished by means of several small, uniform changes, approximating a vertical curve, rather than by one abrupt change. The appearance of the street intersections must also be considered. In short, the appearance of the entire system of grades, as a whole, must be carefully considered, for it is their effect as a whole, and not the effect of any particular detail, that will be noticed.

76. General Methods of Fixing Grades.—There is no established custom among municipal engineers in regard to the amount of grade, and practice varies materially. Indeed, some engineers prefer not to follow the same rule in regard to any two streets, but in each case to establish a grade and harmonize it with that of each intersecting street in such a manner as the conditions of that particular case may seem to demand. This is probably a better practice than to attempt to follow any rigid rule, for a method that would be satisfactory in one case would be likely to prove unsatisfactory in another.

In general, it is a good plan to fix first the grades of the streets extending in one direction, by choosing the direction of the more important streets and taking them in the order of their importance; then fit in the grades of the cross-streets, taking them also in the order of their importance. In fitting in the grades of the cross-streets, it will often be found advisable to modify more or less the grades of the more important ones. If the system of streets is extensive, a contour map will often be of value as an aid in fixing the grades. When the street grades have been finally fixed, the grades of the curbs should be adjusted at the intersections in such a manner as may be best suited to each case.

77. Records of Grades.—A complete and systematic record of all grades should be preserved in a book kept for that

GRADE RECORD

GRADE OF *MAIN STREET* **FROM** *FIRST STREET* **TO** *SECOND STREET*

Station	Left Curb			Roadway			Right Curb			Remarks
	Elevations		Rate of Grade	Elevations		Rate of Grade	Elevations		Rate of Grade	
	Surface	Grade		Surface	Grade		Surface	Grade		
12		108.36	×	108.4	108.36	×		108.36	×	Block line—First Street
13		110.36		110.6	110.36			110.36		
14		112.36	+2.00	112.9	112.36	+2.00		112.36	+2.00	
15		114.36		114.5	114.36			114.36		
+20		114.76		115.0	114.76			114.76		Block line—Second Street
+32		115.00	×	115.0	115.00	×		115.00	×	Curb line—Second Street
+50			0.0	115.1	115.00	0.0			0.0	Center line—Second Street
+68		115.00	×	115.0	115.00	×		115.00	×	Curb line—Second Street
+80		114.70		115.0	114.70			114.70		Block line—Second Street
16		114.20	−2.50	114.6	114.20	−2.50		114.20	−2.50	

FIG. 14

purpose. Such a record is generally known as a **grade record.** For each street on which a grade is established, the grade record should give the rates of grade along the different portions of the street, with the elevation of each station, or, at least, of each street intersection and point where the grade changes. The information given should describe fully the grade of the roadway and that of each curb. This record should be supplemented by a complete and accurate profile of the street. All information should be so well indexed as to be easily and quickly accessible.

78. The book in which the grade records are kept should be made especially for that purpose, with the pages so ruled as to be convenient for recording the grades. The best form for this record book depends somewhat on the engineer's ideas and methods in recording the grades. For most cases, the form given in the sample page, Fig. 14, will be found satisfactory. The notes given are merely for the purpose of illustrating the method of recording the grade. It will be noticed that, in recording the rate of grade, a rising grade is indicated by a + sign, and a falling grade by a – sign; a rate of 0.0 is given for a level grade. In order that each station or plus where the grade changes may be easily distinguished, it is designated by an inclined cross (×) marked in the column for rate of grade.

79. Drawing the Grade.—The ground line of the profile should be carefully studied, as certain limiting points on the grade line may be established by giving attention to the considerations enumerated in the preceding articles. Grade lines can then be drawn in between these points by trial until a final grade is determined that will best fit the conditions.

On roads it is customary to change the grade at some station that is a multiple of 50 or 100 feet. This is purely a matter of convenience, however, in that it facilitates the grade computations when the grade has to be figured for every 50-foot station. The grade is shown only on the profile, according to the method employed in Fig. 8. Elevations are written for all stations of vertical curves and for all points denoting a change of grade.

The rates of grade are written along the grade line where it is uniform for a distance of 100 feet or more.

80. On streets it is customary to make the grade a straight line between the intersecting streets unless a perfectly flat grade would result, in which case it is usually broken to provide for drainage. This is a general principle, but the topography, cost of construction, damage to abutting property, and the general appearance of the street may prevent its adoption in some cases. Furthermore, it will sometimes be necessary to make slight changes in the grade to meet conditions at street intersections, in order to provide intersections that will not only look well, but will take care of the water and be safe to use. The grades for streets should be established and recorded so that the proper grade can be given for new buildings and other structures that may be built in advance of the street improvement.

81. Grades and Drainage of Street Intersections. In order that vehicles may pass smoothly over street intersections, the crown of each roadway should be continuous across the intersection; the crown of either roadway should not be broken by the gutters of the intersecting street. It is evident, however, that some provision must be made for the storm water from the gutters on the upper side of each crown.

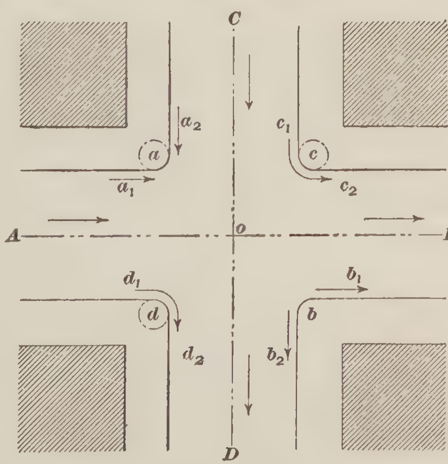


FIG. 15

Each of the intersecting streets shown in Fig. 15 is assumed to have a descending grade in the direction indicated by the arrows marked along its center line, and the crown of each street is assumed to be

continuous. With such grades, the storm water from the gutter c_1 can flow around the curb angle c into the gutter c_2, as indicated by the curved arrow, and, likewise, the storm water from the gutter d_1 can flow around the curb angle d and find an outlet in the gutter d_2. The storm water from the vicinity of the curb angle b can flow away in either gutter b_1 or gutter b_2. In both of the gutters a_1 and a_2, however, the storm water flows toward the curb angle a, and, as there is no gutter leading way from this curb angle across the crown of either roadway, some provision must be made for the storm water from these gutters.

82. If a storm-water sewer extends along either of the intersecting streets, the problem of providing for the storm water at the curb angle a, Fig. 15, may be easily solved by putting a catch basin at the curb angle, as indicated by the dotted circle. The storm water from the gutters a_1 and a_2 would be received directly by the catch basin, from which it would be conveyed to the sewer. Catch basins would also generally be placed at the curb angles c and d to receive the storm water from the gutters c_1 and d_1, so that the gutters c_2 and d_2 would not be overloaded. It is evident that a catch basin would not be required at the curb angle b.

If there is no storm-water sewer along either of the intersecting streets, so that the storm water must be conveyed wholly by the surface gutters, it will be necessary to provide a conduit leading from the gutter at the curb corner a, across and beneath the roadway, and discharging into the descending gutter, as the gutter c_2 or d_2, at some point far enough down to give the required depth below the roadway surface. In some cases, it may be advisable to provide such a conduit under each roadway.

ROAD AND STREET CURVES

83. Road Curves.—In the design of roads, subjected primarily to horse-drawn vehicle traffic, the proper radius of curve would depend principally upon the overall length of the horses and wagon and the width of the road. It has been found that to permit a vehicle drawn by four horses to keep upon a

12-foot roadway requires a curve having an inside radius of about 100 feet. In designing a road that takes either motor-car traffic alone or a combination of motor-car and horse-drawn vehicle traffic, the safety of the traveling public and the wear of the roadway must be considered. Sharp curves are points at which collisions are very liable to occur, particularly if the view is obstructed; it is natural for all traffic to keep to the inside of the curve, and, in the case of motor vehicles, if the speed is not brought down to about 10 to 15 miles an hour, the slew of the vehicles as they pass around the curve tends to grind out the surface of the roadway. The following conclusion was adopted by the First International Road Congress held in Paris in 1908: "The radii of curves should be as great as possible, 164 feet at least; the outside of curves should be slightly raised but so as not to inconvenience ordinary vehicles; no obstructions to the view should be allowed at curves."

84. Street Curves.—Sharp curves on streets are unavoidable, since a rectangular block system always forms a large part of the street plan. The radii of the curves at the corners of the streets will generally vary from about 4 to 12 feet. The corners should have the largest radii possible in order better to accommodate vehicular traffic entering the street.

As previously stated, the use of curves on a park system of roads is desirable from the esthetic standpoint. For instance, a winding road, following the natural contours of the ground along some lake, shore or river bank, tends to emphasize the natural beauties of the surrounding scenery.

CROSS-SECTIONS OF ROADWAYS

85. Variations in Slope and Curvature.—To hasten the removal of the rainwater from the surface and prevent it from soaking into the subsoil, the center of the road is raised above the sides, the amount of rise depending more or less on the character of the surface. There is much difference of opinion as to the amount of rise and the manner in which it should be provided. It should be borne in mind that excessive rise, or

convexity, renders traffic difficult, and is very dangerous on roads that are frozen and slippery; it causes the traffic to follow the center of the roadway, that being the only part where the vehicle can travel upright, and consequently the wear of the road is increased.

On hillside and mountain roads, the surface is sometimes formed of a single slope inclining inwards, in which case the water from the road and slopes of the mountains is conducted by pipes and culverts laid under and across the road. The inner half of such a road is usually subjected to more traffic than the outer half; it is thus worn hollow, retains water, and consequently is difficult to keep in repair.

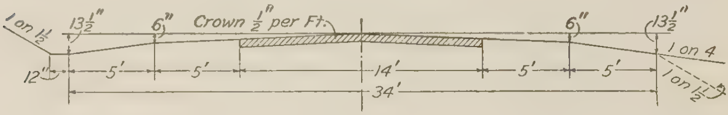


FIG. 16

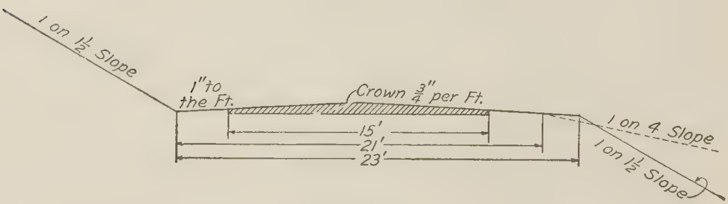


FIG. 17

On roads used by motor vehicles, the cross-slope on curves must be a single slope pitching inwards, and the outer edge should be raised from 4 to 8 inches above the center, the amount depending on the sharpness of the curve.

86. Typical cross-sections adopted by the Highway Departments of New York and Massachusetts are shown in Figs. 16 and 17, respectively. The slope of the banks depends upon the kind of material of which they are composed. As ordinary earth in a dry state has an angle of repose of 1 on $1\frac{1}{2}$, this slope is in common use for embankments and cuts. It is customary in many states to carry out the shoulders of fills less than

4 feet in height with a 1 on 4 slope, which practically renders unnecessary the use of a guard rail.

87. Street Cross-Sections.—A city street is made up of three components: (*a*) The roadway for vehicles; (*b*) the sidewalk or footway for pedestrians; and (*c*) the curb, marking the line between roadway and footway and protecting the latter from vehicular encroachment. In residential districts a fourth part may be added, the street lawn, adjacent to the footway either between the sidewalk and curb, or between the sidewalk and property line. In some cases the lawn may be in the middle of the street, dividing the roadway into two parts and forming a parkway, the roadway consisting in all, of three divisions.

88. It is necessary to provide gutters or side ditches along the outer edges of the roadway to carry away the surface water; and, in order that the water falling on the surface of the roadway may be thrown off into the side gutters, the center of the roadway must be made higher than the outer edges. The form of cross-section that will best satisfy these conditions depends chiefly on the character of the roadway surface and on the nature of the traffic.

89. Until such time as a roadway is paved, its cross-section will have a more or less irregular form, and will but roughly approximate any theoretical figure. Unpaved roadways, however, are generally so laid out and graded as to approximate more or less closely some theoretical form of cross-section. When a street is paved, it is given a definite cross-section, the form of which depends on the kind of pavement, the grade of the roadway, the nature of the traffic, and the ideas of the engineer in charge of the work. Some kind of gutter is always provided along each outer edge of the roadway, and the roadway between the gutters is raised. The roadway is then said to be crowned, and the term crown is applied both to the whole cross-section and to its highest point.

WIDTH OF ROADWAY

90. Minimum Width.—The width of the roadway on country roads should be just sufficient to accommodate conveniently the traffic upon it. Any unnecessary width causes increased cost in construction, while very narrow roads are disadvantageous because they wear badly; since on them the traffic is confined to a single track, thus quickly forming ruts. Experience shows that, if a wide and a narrow road are both subjected to the same amount of traffic, the cost of maintenance is less for the wide than for the narrow road.

The minimum width of the roadway if intended to accommodate two lines of travel is fixed by the width required to allow two vehicles to pass each other safely. This width varies from 18 to 20 feet, depending upon the character and amount of traffic. If the road is intended for a single line of travel, 8 feet is sufficient, but suitable turnouts must be provided at frequent intervals. The roadway on an earth road should be wider than on an improved road, so that the traffic can be spread out and avoid cutting up the road during rainy weather. As the road approaches a town, the width of the roadway should be increased to accommodate the larger amount of traffic.

91. Width of Right of Way.—The entire area of a road included between fence lines is commonly known as the *right of way;* it is so called because it is the strip of land over which a right of ownership must be obtained, by purchase or otherwise, from the owners of the properties over which the road passes. The best width for the right of way of a road is a matter that must be determined by judgment and according to the requirements of each particular case. When possible, it should be sufficient for future widening of the roadway as the traffic increases. The widths of country roads vary greatly. A width of 4 rods, or 66 feet, is common for important roads in some localities. In other places, very narrow roads are not uncommon, some being little more than narrow lanes, probably not more than a rod in width. Roads 3 rods, or $49\frac{1}{2}$ feet, in width are very common.

A width of 66 feet was probably first adopted largely for convenience of measurement and computation, it being the length of a surveyors' chain. It is about as narrow as is generally desirable for northern climates, as the snow drifts caused by the fence lines will often extend across and block the roadway in narrower roads.

92. Width of Streets.—The total width of a street will not necessarily be wholly occupied by the pavements. Indeed, except in important business thoroughfares, it is seldom that the entire width of the street is occupied by the roadway and the sidewalks. As the widths of these can easily be changed whenever the pavement is renewed, they should always correspond with the immediate requirements of the traffic passing over them. The widths should always be sufficient to accommodate the traffic easily, but widths materially greater than this are disadvantageous.

The roadway should be of such width that it will all be used. The width necessary to accommodate the traffic depends on the volume and character of the latter. A width of 80 feet will usually be sufficient for the roadway of a crowded commercial thoroughfare in a large city, while a width of 60 feet will accommodate the traffic of a very important business street. For many business streets, a width of 50 feet will be ample for the roadway, while for others a width of 40 feet will be sufficient. For residence streets, the width of roadway should generally be from 20 to 36 feet, according to the importance of the street and its position with reference to the routes of greatest travel. The widths of the roadways on the important residence streets of American cities of about 100,000 inhabitants are being reduced, as the streets are paved, to from 30 to 34 feet, the widths formerly used having been found to be greater than is required; considerable saving in the cost of paving and maintenance is thus effected by reducing the width. When no portion of the roadway is occupied by street-railway tracks, a width of 24 feet will accommodate a very considerable amount of light traffic, and will be sufficient for many residence streets not situated along the main lines of travel. Even less width

will sometimes be sufficient for roadways in small towns and villages. On streets of light traffic, the roadway should be narrowed to the width really required; this will permit the roadway to be much better improved with the funds available than would be possible with a wider roadway.

93. There are several advantages in favor of the smaller width of roadways. If the distance between property lines is 60 feet and a 20-foot roadway is constructed, a space of 40 feet is left available for sidewalks and parking. With a width of 12 feet for each sidewalk, a parking space 8 feet wide could be constructed beyond the sidewalk on each side. This space, if properly treated, would add greatly to the appearance of the street. By reducing the width of roadway, the first cost of construction and later maintenance costs are materially reduced. The width of 20 feet is ample for two vehicles to pass or one to pass when the other is backed against the curb. The parking spaces would be available for the location of underground services, and thus frequent disturbances to the roadway could be avoided. Street widths are generally stated as the distance between property lines. The width taken by each sidewalk in city streets is from one-fourth to one-fifth the total distance between property lines, although this may be reduced in some instances.

CROWNS OF ROADWAYS

94. Height of Crown.—The height of the crown above a straight line through the outer edges of the roadway, or bottoms of the gutters, will here be designated the *height of crown*. The height of crown that will efficiently throw off the surface water into the side gutters and at the same time cause no inconvenience to the traffic depends chiefly on the character of the roadway surface and its grade. The crown or lateral slope of the roadway should never be so great as to produce inconvenient tipping of vehicles in driving on the side of the roadway, as this will cause the traffic to follow the center of the roadway, thereby rapidly wearing away that portion and destroying the crown. The more smooth and perfect the roadway surface, the more

easily will the water flow off, and, consequently, the less will it need to be crowned.

For paved roadways, the height of crown, and, therefore, the lateral slope, should be less on steep than on flat or level grades. This will make the roadway surface somewhat less slippery and inconvenient for travel on steep grades, while there will gener-

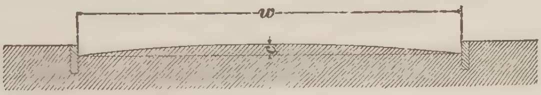


FIG. 18

ally be no difficulty about the water reaching the gutters without damage to a paved roadway. On the other hand, an earth or gravel roadway is likely to become damaged by the water following the roadway and washing out gulleys and channels in flowing down steep inclines; therefore the height of crown of such a roadway should be increased on steep grades, in order to throw the water more quickly into the side gutters and as far as possible prevent it from flowing down the roadway. In spite of such precaution, however, if the roadway is not constantly kept in good repair, water will flow along in the wheel ruts and in the depressions worn by the horses' feet, and do more or less damage on steep inclines.

95. Form of Crown.—With reference to the manner in which the roadway is crowned, two forms of cross-section are advocated and used. In one form, the surface line of the cross-

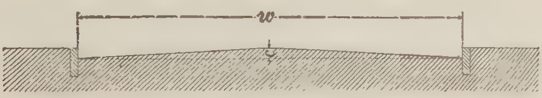


FIG. 19

section is the arc of a circle or of some other curve, usually a parabola. This form of cross-section is shown in Fig. 18 and will here be called a *curved crown*. In this and the following illustrations, c indicates the height of the crown and w the width of the roadway. As will be noticed in the figure, the roadway surface has a much greater lateral slope near the outer edges than it has near the center. The effect of this is

to cause the greater part of the traffic to follow the center of the roadway, producing the greatest wear on that part.

In the other form of cross-section, the surface line consists of two straight lines having the proper inclination and connected by a short curve at the center of the roadway, as shown in Fig. 19. In this form of cross-section, which will be called a *straight-line crown*, the lateral slope of each side of the roadway extends uniformly to the gutter, and the width of the nearly level portion at the center is greatly reduced. This insures a more efficient drainage and at the same time permits vehicles to drive close to the curbing with nearly as much comfort as on any other portion of the roadway.

96. Prior to 1910, crowns for roadways outside of urban districts were usually constructed with two intersecting straight lines, as shown in Figs. 16, 17, and 19, while pavements in cities were invariably built with curved crowns, usually parabolic, as in Fig. 18. Since 1910, there has been a general tendency to adopt the intersecting straight-line crown in municipal work as well as in state and county work, the rate of slope varying with the type of roadway.

97. In its 1918 Report,* the Special Committee on Materials for Road Construction, of the American Society of Civil Engineers, recommended the maximum and minimum values for straight-line crowns for different types of roads and pavements, shown in Table III.

98. Elevations on Cross-Section.—In laying out the cross-section of a roadway, it is necessary to determine the elevations of the surface at different points across the roadway. In almost all cases, whether the roadways have curved or straight-line crowns, the summit of the crown is at the center of the roadway, and the slopes of the sides are symmetrical with reference to the center. Such a crown will here be called a *symmetrical crown*. In this and the following articles, only symmetrical crowns are considered.

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* Trans. Am. Soc. C. E., Vol. LXXXII, page 1393.

TABLE III

MAXIMUM AND MINIMUM STRAIGHT-LINE CROWNS FOR ROADS AND PAVEMENTS

Kind of Roadway	Maximum Crown Inches Per Foot	Minimum Crown Inches Per Foot
Asphalt block	$\frac{1}{4}$	$\frac{1}{8}$
Bituminous surface	$\frac{1}{2}$	$\frac{1}{4}$
Bituminous concrete	$\frac{1}{2}$	$\frac{1}{4}$
Bituminous macadam	$\frac{1}{2}$	$\frac{1}{4}$
Brick	$\frac{3}{8}$	$\frac{1}{8}$
Broken stone	$\frac{3}{4}$	$\frac{1}{2}$
Cement-concrete	$\frac{3}{8}$	$\frac{1}{4}$
Gravel	1	$\frac{1}{2}$
Sheet asphalt	$\frac{1}{4}$	$\frac{1}{8}$
Stone block	$\frac{1}{2}$	$\frac{1}{4}$
Wood block	$\frac{1}{4}$	$\frac{1}{8}$

EXAMPLE.—(*a*) What is the maximum height of crown for a 60-foot bituminous concrete roadway? (*b*) What is the minimum height of crown for that roadway?

SOLUTION.—(*a*) The half width of roadway is 30 ft. According to Table III the maximum crown for bituminous concrete is $\frac{1}{2}$ in. to the foot. Therefore, the maximum height of crown is $\frac{1}{2}\times 30 = 15$ in. $= 1.25$ ft. Ans. (*b*) From the same table, the minimum crown is $\frac{1}{4}$ in. to the foot. Therefore, the minimum height of crown is $\frac{1}{4}\times 30 = 7.5$ in. $= .625$ ft. Ans.

The grade line of a roadway represents the elevation of the summit of the crown. Consequently, for any cross-section having a symmetrical crown, the elevation of the roadway surface at the center is given directly by the grade line, and the elevation of any other point in the surface of the cross-section must be referred to the elevation of grade and determined by its distance below the grade line. The distance of any point in the surface of the cross-section below the grade line or summit of the crown may be easily determined by means of the coordinates of the point, taking the origin at the summit of the crown.

99. Coordinates to Curved Crown.—For a cross-section having a curved surface line, as shown in Fig. 18, a good form is given by a circular curve. The equation of the curve, however, will be somewhat simpler for a parabolic than for a circular curve. Since, for a flat arc, the two curves are practically identical, the parabolic curve is used. With this curve, if, as in Fig. 20, x and y are, respectively, the abscissa and the ordinate to any point p in the surface line of the cross-section, with the origin at the center o, the value of y, or the distance of the given point p below a horizontal line tangent to the roadway surface at the center, will be given by the formula,

$$y = \frac{4\,c\,x^2}{w^2}$$

In this formula, w is the width of roadway and c is the height of crown. When a curved crown is employed, the height of crown

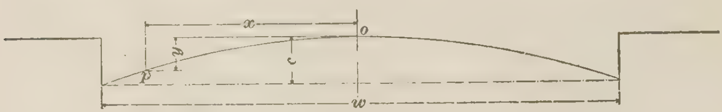

Fig. 20

is usually taken per foot of half width of road as follows: Macadam, $\frac{1}{2}$ inch; stone block, $\frac{3}{8}$ inch; brick, $\frac{5}{16}$ inch; sheet asphalt, $\frac{5}{16}$ inch; wood block, $\frac{1}{4}$ inch.

100. Example of Coordinates to Curved Crown. As an illustration let it be required to find the ordinates to the surface line of the cross-section at distances of 5, 10, 15, 20, and 25 feet on each side of the center of a macadam roadway 60 feet wide. According to Art. **99**, the height of crown is $\frac{1}{2} \times 30 = 15$ inches, or 1.25 feet. Applying the formula of Art. **99** the following results are obtained:

At 5 feet on either side of the center, $y = \frac{4 \times 1.25 \times 5^2}{60^2} = .035$ foot.

At 10 feet on either side of the center, $y = \frac{4 \times 1.25 \times 10^2}{60^2} = .139$ foot.

At 15 feet on either side of the center, $y = \frac{4 \times 1.25 \times 15^2}{60^2} = .313$ foot.

At 20 feet on either side of the center, $y = \frac{4 \times 1.25 \times 20^2}{60^2} = .556$ foot.

At 25 feet on either side of the center, $y = \frac{4 \times 1.25 \times 25^2}{60^2} = .868$ foot.

EXAMPLES FOR PRACTICE

1. (*a*) What is the maximum height of crown for a cement-concrete roadway 24 feet wide with a straight-line crown? (*b*) What is the minimum height of crown for that roadway?

Ans. $\begin{cases} (a)\ .375 \text{ ft.} \\ (b)\ .250 \text{ ft.} \end{cases}$

2. A sheet-asphalt pavement 48 feet wide is to have a curved crown. What will be the ordinates to the surface line at points in the cross-section which are distant from the center: (*a*) 24 feet? (*b*) 12 feet? (*c*) 6 feet?

Ans. $\begin{cases} (a)\ .625 \text{ ft.} \\ (b)\ .156 \text{ ft.} \\ (c)\ .039 \text{ ft.} \end{cases}$

HIGHWAYS
(PART 2)

SELECTION OF ROADWAY TYPE

FACTORS DETERMINING CHOICE OF ROADWAY

DURABILITY, SUITABLE SURFACE, SANITARY QUALITIES

1. Introductory.—The determination of what is the most economical and efficient type of roadway to be employed on different highways is one of the most important subjects that the highway engineer has to consider. The solution of the problem depends upon many variable factors, to all of which due consideration must be given and the proper value must be attached to each. The great variety of materials and methods of construction and maintenance used makes it a difficult matter to reduce all of the different types of roads and pavements to a comparable basis for a given location.

2. Essentials of an Ideal Roadway.—An ideal road or pavement should be durable, noiseless, easily cleaned, adapted to the grade, non-slippery for horses and all classes of vehicles under varying climatic conditions, easily maintained, should yield neither dust nor mud, be impervious to water, have a low

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tractive resistance, low first cost, low annual cost, low maintenance charge, and a surface pleasing to the eye.

3. Durability.—The life of a road or pavement may be expressed in one of the following terms: (*a*) The number of years during which it can be maintained in a satisfactory condition before the cost of maintenance per year has reached such an amount as to make reconstruction more economical. (*b*) The total number of tons per yard or foot of width that the road or pavement is subjected to during its life. As durability depends upon a number of variables, among which the amount of traffic is of primary importance, method (*b*) usually conveys more information than method (*a*).

Based on the practice in central western cities, method (*a*) has been employed by Fixmer in assigning the values given in Table I for the life of several types of roads and pavements. In each case the estimated life is based on the supposition that the pavement is used under suitable local conditions.

TABLE I

DURABILITY OF VARIOUS ROADS AND PAVEMENTS

Type of Road or Pavement	Duration Years
Granite block	30
Creosoted wood block	15–20
Brick	20
Sheet asphalt	16
Asphaltic concrete	12–20
Cement-concrete	6–10
Bituminous macadam	8
Broken stone	4

John A. Brodie, City Engineer of Liverpool, England, employed method (*b*) in making the following comparison of the tonnage life of different kinds of stone-block pavements and broken-stone roads.

"Taking heavy-traffic streets first, experience shows that accurately dressed setts, or stone blocks—6 inches deep by 6 inches to 8 inches long by 4 inches wide, laid on a sound concrete foundation, at least 8 inches deep, with a small sand bed between the under side of the sett and the concrete, the joints being thoroughly packed with hard gravel and afterwards grouted with a permanent pitch mixture, which prevents any movement in the stones, and renders the whole surface perfectly impervious to weather—give a life equal to at least seven and one-half million tons per yard width, and under these conditions this life has often been exceeded.

"When the same quality of stone is used in ordinary macadam laid 6 inches to 7 inches deep on a sound, hand-packed foundation, experience shows that the tonnage-life of the surface before requiring to be recoated is enormously decreased, and instead of seven and one-half millions, a figure of about 100,000 tons only, or about 75 times less than the result for setts previously given, has been obtained on a street of moderate traffic—a somewhat startling difference."

4. Sanitary Qualities.—The sanitary condition of a road or pavement depends on its imperviousness, smoothness, and freedom from dust and mud. From the standpoint of the public health, noiselessness might properly be included under this head, as it affects the health of nervous people. Tillson states that, "Of the different kinds of pavements herein stated, one of wood blocks is least noisy, followed by asphalt, asphalt block, bitulithic, brick, and granite as the most noisy."

The several roads and pavements may be classified as follows, the groups being given in the order of their desirable sanitary properties: (1) sheet asphalt, bituminous concrete, and cement-concrete; (2) creosoted wood block, bituminous macadam, bituminous surface, stone block and brick with well-filled joints; (3) broken stone, gravel, earth, stone block, and brick with open joints.

5. Slipperiness.—The comparison of pavements from the standpoint of slipperiness has naturally been confined by early investigators to the effect on horses. It is evident that future

investigations along this line should include consideration of slipperiness for all classes of vehicles under varying climatic conditions. From the former viewpoint, that is, with reference to horses, stone block with joints filled with a bituminous filler ranks first as a non-slippery pavement. Vitrified brick constructed with a bituminous filler is adaptable for steep grades. The other pavements and roads rank in the following order as non-slippery: Gravel, broken stone, bituminous concrete, bituminous macadam, stone block and brick with cement-grouted joints, cement-concrete, bituminous surfaces, sheet asphalt, and wood block.

RESISTANCE TO TRACTION

6. Classification.—The forces that offer resistance to the motion of vehicles on roadways may be classified under the following heads:

1. *Air resistance,* which includes both the friction caused by the air and the direct resistance that the air offers to displacement.

2. *Friction,* which comprises (*a*) friction of the axles, and (*b*) friction between the wheel tires and the surface of the roadway. The latter form is termed rolling friction.

3. *Gravity,* which comprises (*a*) the resistance due to the grade or inclination of the roadway, and (*b*) collision, or the resistance offered by obstacles on the surface of the roadway.

7. Air Resistance.—The resistance offered by the air varies according to the velocity and direction of the wind, the area of the surface acted on, and the velocity of the vehicle. The pressure of the wind at a velocity of 15 miles an hour, which corresponds to a pleasant breeze, is equal to about 1 pound per square foot; at a velocity of 50 miles an hour, which is equivalent to a violent storm, it is equal to about 12 pounds per square foot.

8. Axle Friction.—The resistance arising from the friction of the axles depends on the magnitude of the load, the area of the bearing surface of the axle, and the nature and

degree of lubrication. It is entirely independent of the condition of the road surface, and is negligible in amount. With wheels of ordinary construction, it amounts to from $\frac{1}{130}$ to $\frac{1}{100}$ of the weight on the axle. As axle friction and the resistance of the air are constant and entirely independent of the condition of the road, their effects may be, and usually are, neglected in the construction of roads.

9. Rolling Friction.—Resistance to rolling is divided into two classes: (1) Friction arising from the mere contact of the wheel tire with the surface of the road; and (2) friction caused by the yielding quality of the road and its foundation. The latter form of friction is termed *friction, or resistance, of penetration.* The first-mentioned form will here be called *rolling friction proper.*

10. Rolling Friction Proper.—The resistance arising from the mere contact between the road surface and the wheel tire varies according to the character of the road surface, the width of the tire, and the diameter of the wheel, and can be determined only by experiment in each particular case.

Numerous experiments have been made to determine the rolling friction offered by a load hauled on various road surfaces. The results, which are shown in Table II, vary through a wide range, as is to be expected when the many different conditions that may affect them are taken into consideration. This table has been compiled from various sources, and is believed to represent fairly the results of the experiments that have been made; it gives the approximate maximum, minimum, and mean rolling friction in pounds, caused by a load of 1 gross ton (2,240 pounds) hauled at an ordinary pace on level road surfaces of the kinds named, and also the mean friction in fractional parts of the load.

The force t required to overcome the total frictional resistance on a level road is given by the general formula

$$t = c\,W$$

in which W = load moved;

c = value given in the last column of Table II for the various kinds of road surfaces.

The force t and the load W should be expressed in terms of the same unit, as the pound or the ton. The constant c is called the *coefficient of rolling friction.*

TABLE II

ROLLING FRICTION FOR DIFFERENT ROADWAY SURFACES

Character of Roadway Surface	Rolling Friction			
	Pounds per Gross Ton			Mean in Terms of Load Values of c
	Maximum	Minimum	Mean	
Earth, ordinary	300	125	200	$\frac{1}{11}$
Earth, dry and hard	125	75	100	$\frac{1}{22}$
Gravel, common	147	140	143	$\frac{1}{16}$
Gravel, hard rolled			75	$\frac{1}{30}$
Macadam, ordinary	140	60	90	$\frac{1}{25}$
Macadam, good	80	41	60	$\frac{1}{37}$
Macadam, best	64	30	50	$\frac{1}{45}$
Cobblestone, ordinary			140	$\frac{1}{16}$
Cobblestone, good			75	$\frac{1}{30}$
Granite block, ordinary			90	$\frac{1}{25}$
Granite block, good	80	45	56	$\frac{1}{40}$
Granite block, best	40	25	34	$\frac{1}{66}$
Belgian block, ordinary			56	$\frac{1}{40}$
Belgian block, good	50	26	38	$\frac{1}{60}$
Plank	56	32	44	$\frac{1}{50}$
Wooden block, in good condition	40	20	30	$\frac{1}{75}$
Asphalt	39	15	22	$\frac{1}{100}$

11. The resistance to rolling is, under some conditions, affected by the width of the wheel tire. On hard and incompressible surfaces, the resistance is practically independent of the width of the tire, while on soft, compressible surfaces the resistance decreases as the width of the tire increases, except

when the surface is composed of deep sticky mud that adheres to the wheel, in which case a narrow tire causes less resistance.

Many tests have been made to determine the best width of tire and the proper load for a given width of tire. The results differ, but they all indicate that to make the tire wider than 6 inches does not diminish the force required to move the load, and unnecessarily increases the dead weight of the vehicles; and that a width of less than 2 inches causes the wheels to cut into the road surface and form ruts that each succeeding vehicle deepens.

The best width of tire will depend on the weight of the load and on the character and condition of the roadway surface; and as these vary greatly, no general rule can be stated for the width of tire that will be entirely satisfactory.

12. Friction of Penetration.—The friction of penetration is produced by a weak or yielding road; that is, one on which the wheel sinks or penetrates below the surface, leaving a track or rut behind it, and forming a hollow or cavity under it, up which the load has to be lifted, as indicated in Fig. 1. The wheel is thus continuously climbing a slight inclination, or, more correctly, is constantly compressing new material. The resistance due to penetration is less for large than for small wheels, and is measured by the force that, applied horizontally at the axle, is necessary to pull the load up the inclined surface, or to compress the supporting surface. The magnitude of this force varies with the diameter of the wheel, the width of the tire, the speed, the presence or absence of springs, and the nature of the roadway surface. If the surface of the road is soft, sticky clay, or loose sand or gravel, the force required will be increased considerably by the friction on the submerged sides of the wheel.

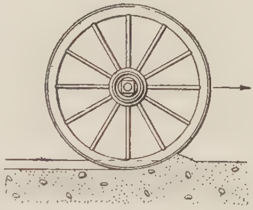

FIG. 1

13. Grade Resistance.—Grade resistance is due to the grade of the road, that is, to the longitudinal inclination of the roadway to the horizontal. It is the same on both good and

bad roadways, and, unlike the resistances previously described, can be determined exactly from the laws of mechanics.

Fig. 2 represents a wheel on an inclined plane $B\ C$, whose inclination to the horizontal is the angle $A\ C\ B = x$. The weight on the wheel c is w, represented graphically by the line $c\ b$. According to the principle of the parallelogram of forces, the weight w may be resolved into the two forces $c\ a = w_1$ and $c\ d = t_1$, the former perpendicular and the latter parallel to $B\ C$. The angles $a\ c\ b$ and $c\ b\ d$ are each equal to $A\ C\ B$, their sides being perpendicular to the sides of $A\ C\ B$. Also, $c\ a = b\ d$, as these two lines are opposite sides of the parallelogram $c\ a\ b\ d$.

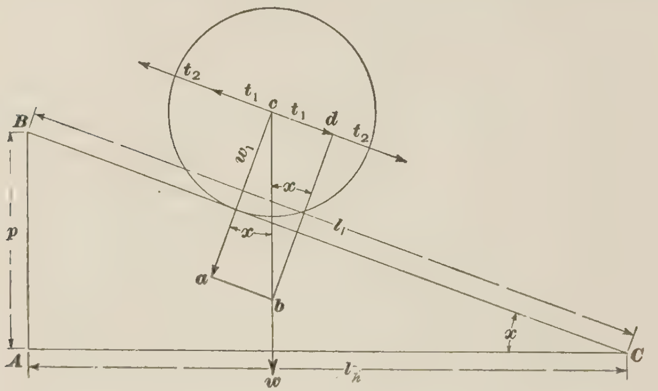

FIG. 2

The components t_1 and w_1 are easily found by solving the right triangle $c\ b\ d$, as follows:

$$t_1 = c\ d = c\ b \sin x = w \sin x \qquad (1)$$

$$w_1 = d\ b = c\ b \cos x = w \cos x \qquad (2)$$

The force t_1 is the resistance due to the inclination of the surface $B\ C$, and is independent of the friction. The force w_1, being the normal pressure on the plane, causes a frictional resistance t_2 equal to the coefficient of friction c multiplied by w_1; that is,

$$t_2 = c\ w_1 = c\ w \cos x \qquad (3)$$

If T is the total tractive force necessary to just pull the wheel up the plane, then

$$T=t_1+t_2=w\ (\sin x+c\cos x)^* \qquad (4)$$

An expression for the force necessary to prevent the wheel from rolling down the plane is obtained as follows: The direct force pulling the wheel down is t_1; but in this case the frictional resistance t_2 opposes the downward motion. The resultant force T_1 acting down the plane (which is the one that must be applied in an opposite direction to keep the wheel from moving downwards) is, therefore,

$$T_1=t_1-t_2=w\ (\sin x-c\cos x) \qquad (5)$$

Let the total rise $A\,B=p$, the inclined length $B\,C=l_i$ and the horizontal length $A\,C=l_h$, then the values of t_1, w_1, and t_2 become:

$$t_1=\frac{w\,p}{l_i}=\frac{w\,p}{\sqrt{p^2+l_h^2}} \qquad (6)$$

$$w_1=\frac{w\,l_h}{l_i}=\frac{w l_h}{\sqrt{p^2+l_h^2}}=t_1\times\frac{l_h}{p} \qquad (7)$$

$$t_2=\frac{c\,w\,l_h}{l_i}=\frac{c\,w\,l_h}{\sqrt{p^2+l_h^2}}=c\,t_1\times\frac{l_h}{p} \qquad (8)$$

from which corresponding values can be written for T and T_1.

14. Approximate Formulas for Finding Grade Resistance.—Where the inclination is small, l_i is nearly equal to l_h, and therefore, approximately, $t_1=\frac{w\,p}{l_h}=w\times\frac{p}{l_h}$; $w_1=w$; $t_2=c\,w$ (compare formula of Art. **10**). The quantity $\frac{p}{l_h}$ represents the rate of rise, or grade, per unit of horizontal length.

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*The force T is really only sufficient to balance the resistances; in order that there may be motion, the tractive force must exceed T. But, as any excess of the tractive force over T, no matter how small, will produce motion, it is usually said that T is the force necessary to pull the load up the plane.

The rate per 100, or per cent., is evidently $100 \times \frac{p}{l_h}$. If the rate per unit is denoted by r_1, and the per cent. rate by r_{100}, there results

$$r_1 = \frac{p}{l_h} \tag{1}$$

$$r_{100} = 100 r_1 = \frac{100p}{l_h} \tag{2}$$

$$\frac{p}{l_h} = r_1 = \frac{r_{100}}{100} \tag{3}$$

Therefore,
$$t_1 = w\frac{p}{l_h} = w\,r_1 = w\frac{r_{100}}{100} \tag{4}$$

Also,
$$T = t_1 + t_2 = w\left(\frac{p}{l_h} + c\right) = w\left(\frac{r_{100}}{100} + c\right) \tag{5}$$

$$T_1 = t_1 - t_2 = w\left(\frac{p}{l_h} - c\right) = w\left(\frac{r_{100}}{100} - c\right) \tag{6}$$

If $r_{100} = 1$, and $w = 2{,}000$ pounds, or 1 ton, formula **4** gives $t_1 = 2{,}000 \times \frac{1}{100} = 20$ pounds. That is, the grade resistance on a grade of 1 per cent. is 20 pounds for each ton of load hauled. This is a useful value, which should be memorized.

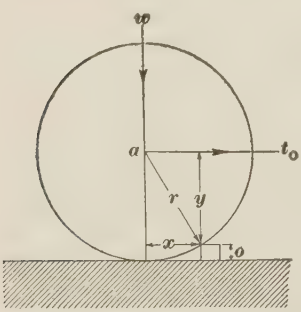

Fig. 3

15. Collision.—Collision is caused by obstacles, such as stones lying on or protruding through the surface, contact with which produces a sudden checking of the forward movement, and requires the load to be lifted over them. The force required to lift the load is measured by the horizontal force that, applied at the axle, is sufficient to raise the load on the wheel to the height of the obstacle. In Fig. 3, the tractive force t_o and the load w are both applied on the wheel a. From the theory of moments, it is known that, in order that the tractive force t_o may be

sufficient to balance, on the obstacle o, the wheel supporting the weight w, the moment of the force t_o acting with the lever arm y must be equal to the moment of the force w acting with the lever arm x; or, algebraically $t_o y = w\,x$.

Therefore, $$t_o = \frac{w\,x}{y}$$

If the radius of the wheel is denoted by r, and the height of the obstacle by o, we have $y = r - o$, and $x = \sqrt{r^2 - y^2} = \sqrt{r^2 - (r\text{-}o)^2} = \sqrt{(2r - o)o}$;

therefore, $$t_o = \frac{w\sqrt{(2r - o)o}}{r - o}$$

The value t_o, as given by this formula, measures the resistance of the obstacle, and any tractive force greater than t_o will pull the wheel over the obstacle. For small obstacles, this resistance may be considered to be inversely proportional to the square root of the diameter of the wheel. It should be noted, however, that the resistance of small obstacles and inequalities in the roadway surface is due largely to the shock that they produce, and is greater at high than at low speeds.

Example 1.—What is the total tractive force required to haul a load of 5,000 pounds on an ordinary macadam roadway having an ascending grade of 4 per cent.?

Solution.—As obtained from Table II, the value of c for ordinary macadam roadways is $\frac{1}{25} = .04$. By formula **5**, Art. **14**, $T = 5{,}000\left(\frac{4}{100} + .04\right) = 400$ lb. Ans.

Example 2.—What is the tractive force required to draw a wheel 5 feet in diameter, supporting a load of 400 pounds, over an obstacle 6 inches (= .5 foot) in height resting on a level roadway surface?

Solution.—The radius of the wheel is one-half the diameter, or 2.5 ft. By the formula of Art. **15**, the tractive force t_o is

$$\frac{400 \times \sqrt{(5 - .5) \times .5}}{2.5 - .5} = 300 \text{ lb.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

1. What is the total tractive force required to haul a load of 6,400 pounds on a roadway paved with asphalt, and having an ascending grade of 2 per cent.? Ans. 192 lb.

2. What is the total tractive force required to haul a load of 3 gross tons on a roadway paved with good granite blocks, and having an ascending grade of 5 per cent.? Ans. 504 lb.

3. What is the total tractive force required to haul a load of 4,800 pounds on a hard-rolled gravel roadway having a grade of 3 per cent.? Ans. 304 lb.

4. What is the total tractive force required to haul a load of 2 gross tons on an ordinary earth roadway having a grade of 10 per cent.? Ans. 855 lb.

5. What is the tractive force required to draw a wheel 4 feet in diameter, supporting a load of 200 pounds, over an obstacle .4 foot in height, resting on a level roadway surface? Ans. 150 lb.

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16. Maximum and Minimum Grades.—In its 1918 Report*, the Special Committee on Materials for Road Construction, of the American Society of Civil Engineers, states that conservative practice fixes the maximum grades for satisfactory results as shown in Table III, and the minimum grades according to the conditions given in the following statement:

"The minimum grades allowable will depend on local conditions as to climate, type of construction, character and amount of traffic, conditions of underlying and adjacent soil, and such other circumstances as affect drainage. Except for roadways on fills, where the outside edges of the surfaces of the shoulders are at least 2 feet above the level of the adjacent ground or water level, or except in cases where the roadway is laid over sand of such a character that it never becomes water-logged, a longitudinal grade for the roadway of less than one-half of 1 per cent. should not be used for roads.

"On streets, where the smoothness and evenness of the roadway surface may be confidently expected to be the greatest, and where conformity to the proposed elevations of surface is more carefully sought and more accurately possible, a minimum grade of as low as one-quarter of 1 per cent. has sometimes given

* Proc., Am. Soc. C. E., December, 1917, p. 2331.

satisfactory results in an emergency; but a minimum of one-half of 1 per cent. would be better as an established standard."

TABLE III

MAXIMUM GRADES FOR VARIOUS KINDS OF ROADWAYS

Kind of Roadway	Maximum Grade Per Cent.
Asphalt block	8.0
Bituminous surfaces	6.0
Bituminous concrete	8.0
Bituminous macadam	8.0
Brick — cement filler	6.0
Brick — bituminous filler	12.0
Brick — "Hillside" block	15.0
Broken stone	12.0
Cement-concrete	8.0
Gravel	12.0
Sheet asphalt	5.0
Stone block — cement filler	9.0
Stone block — bituminous filler	15.0
Wood block	4.0

17. Tractive Power of Horses.—The load that a horse can pull on a given road surface is dependent on the weight of the animal, the quality of the foothold afforded by the road surface, the speed, and the duration of the effort. Owing to the difference in weight, strength, and training, the work that can be performed by different animals varies greatly, and it is possible to make only a roughly approximate statement with regard to the average amount of work a horse can do.

It is considered that a good average horse, weighing 1,200 pounds and traveling at a speed of 2.5 miles per hour, or 220 feet per minute, can exert on a smooth level road a pull or tractive force of 100 pounds, which is equivalent to $100 \times 220 = 22{,}000$ foot-pounds of work per minute. This represents

the work of a rather superior animal, however, and it will probably be more correct to assume that the average horse, working regularly 10 hours a day, can exert a tractive force of 90 pounds when traveling on an ordinary level roadway at a speed of 2.5 miles per hour. This is equivalent to $90 \times 220 = 19{,}800$ or, say, 20,000 foot-pounds of work per minute. This value will here be used. Hence, for moderate speeds, the average tractive force that can be exerted by a horse will be given by the formula

$$t' = \frac{20{,}000}{s'}$$

in which t' = average tractive force, in pounds;
s' = speed, in feet per minute.

If the tractive force t' is known, the average speed s' at which a certain load can be transported may be computed by this formula.

18. The work done by a horse is greatest when he moves at a speed of about one-eighth the greatest speed with which he can move when drawing no load; this will be called the *speed of greatest work*. The force exerted at this speed is about .45 of the utmost tractive force that the animal can exert at a dead pull. From this, it may be seen that a horse can exert for a short time a tractive force of about double that which he can exert continuously, so that much heavier loads can be hauled over steep short grades than over the same grades if long.

ANNUAL COST

19. Factors Determining Annual Cost.—The relative economy of different types of roads and pavements can be ascertained only by comparing the annual costs. The annual cost is a combination of the following variables: (*a*) Interest on the initial cost of the roadway; (*b*) the annual maintenance charge, and (*c*) an annuity which will in *N* years, the so-called life of the road, provide a fund equal to the cost of reconstruction.

Let C = annual cost, in dollars per square yard;
A = first cost, in dollars per square yard;
I = annual maintenance charge, in dollars per square yard;
r = rate of interest, expressed decimally;
x = annuity, in dollars per square yard.

Then, $$C = A\,r + I + x$$

In the case of types of roads permitting partial reconstruction every M years, a second annuity x_1, which will provide in M years a fund equal to the cost of partial reconstruction, should also be included in the preceding formula. In order to make a fair comparison of the different methods, the same standard of maintenance should be used in each case.

20. Although, theoretically, the pavement giving the lowest annual cost would be the most economical one to build, there are other financial considerations which sometimes make it necessary to select some other type of pavement. For instance, the amount of money at hand for the improvement may not be sufficient to pay for the first cost of construction of a pavement that would give the lowest annual cost. Again, a road or pavement that might be the most economical one would require such frequent repairs as to interfere with the traffic and business conducted on it.

The annual maintenance charge I and the annuity x are variable factors to which it is difficult to assign definite values in many cases. First cost A, although varying to a marked degree for different classes of pavements in various localities, may be definitely ascertained.

21. Maintenance.—Unfortunately the standards of maintenance vary widely throughout this country. Hence, reports relative to the cost of this item as a factor of annual cost are of little value except in those cases where it is known what the highway officials mean by the statement, "The road is well maintained." The ideal maintenance, which should be striven for in every case, is a method by which the surface of the highway is kept in as good condition as when accepted on the completion of construction. It is self-evident that it is possible to conform

to this ideal only by the adoption of the principle of continuous maintenance.

22. Annuity.—The relation between the annuity and the life of the road or pavement, which was defined in Art. **3**, may be expressed by the formula

$$x = \frac{A\,r}{(1+r)^N - 1}$$

where x = annuity, in dollars per square yard;
A = first cost, in dollars per square yard;
r = rate of interest, expressed decimally;
N = number of years in the period of the annuity.

23. Calculation of Annual Cost.—As an illustration of the application of the formula of Art. **19**, the annual cost of a granite-block pavement laid on a 6-inch concrete base will be computed. It will be assumed that the first cost is \$3.50 per square yard; interest, 4 per cent.; annual maintenance cost, 2.4 cents per square yard; life, 25 years. It will be further assumed that at the end of this period new blocks will be laid on the old concrete foundation at a cost of \$2.50 per square yard, and that in this manner the life of the pavement will be renewed for another 25 years.

By the formula in the preceding article, the annuity for renewal at the end of 50 years is

$$x = \frac{\$3.50 \times .04}{(1+.04)^{50} - 1} = \$.023$$

and the annuity for resurfacing at the end of the first 25 years is

$$x_1 = \frac{\$2.50 \times .04}{(1+.04)^{25} - 1} = \$.060$$

Then, by the formula of Art. **19**, the annual cost per square yard for 50 years, considering the whole pavement to be renewed at the end of that period, is as follows:

$$C_1 = \$3.50 \times .04 + .024 + .023 + .060 = \$.247 \text{ for first 25 years;}$$
$$C_2 = C_1 - x_1 = .247 - .060 = \$.187 \text{ for second 25 years}$$

The mean of these gives

$$C = \frac{\$.247 + \$.187}{2} = \$.217, \text{ average annual cost for 50 years}$$

METHODS OF COMPARISON AND SELECTION

24. Relative Values of Roads and Pavements. The primary object of a detailed comparison of the relative merits of various roads and pavements is to enable the engineer to determine within certain limits the method of construction and, in some cases, the method of maintenance that are adaptable to local conditions from the standpoints of economy and efficiency.

As an aid in comparison, it is advisable to have at hand a table covering numerical values of certain factors that are susceptible to such forms of comparison. Table IV, which

TABLE IV

NUMERICAL VALUES OF VARIOUS ROAD CHARACTERISTICS

	Ideal Pavement	Sheet Asphalt	Brick on Concrete	Stone Block on Concrete	Wood Block on Concrete	Cement-Concrete	Bituminous Concrete	Bituminous Macadam	Bituminous Surface on Broken Stone	Broken Stone With Dust Palliative	Broken Stone	Gravel	Earth
First cost	10	3	5	1	1	6	7	7	8	9	9	9	10
Ease of traction . .	10	10	8	3	9	9	9	8	8	6	6	5	2
Non-slipperiness . .	10	4	8	7	4	6	7	7	7	8	10	10	10
Ease of cleaning . .	10	10	9	7	9	8	9	9	9	3	3	1	1
Noiselessness . . .	10	7	6	3	9	6	9	9	9	10	10	10	10
Non-productive of dust	10	10	9	8	7	7	9	8	8	6	4	3	1

illustrates the treatment of the problem along these lines of investigation, gives assigned values for some of these characteristics of the different types of roads and pavements on the basis of 10 for the value of each characteristic in an ideal pavement. Thus examining, for instance, the factors for an earth road, it is found that as regards the points of first cost, non-slipperiness, and noiselessness the values given correspond with those for an ideal road, while the values for the remaining three factors are the lowest.

25. It is necessary for each engineer to modify tabular information of the kind presented in Table IV in order that the values shall be based upon local conditions. For instance, it is obvious that the numerical values assigned to first cost will vary materially in different sections. It is likewise apparent that it is impracticable blindly to add up numerical values with the expectation that the type having the highest value is to be employed. Also, in the great majority of cases one or more factors will have a greater weight than certain other properties. Of course it is possible to assign weights to the different values of a table and then obtain totals for comparison. The totals obtained by the summation of numerical values of properties referred to in Table IV must, however, be supplemented by values attributed to factors that are not covered in the table, because of their complex and variable character. As examples of such factors may be cited cost of maintenance, durability, etc., which properties are intimately related to local conditions pertaining to a given highway.

26. Some engineers develop a classification for local conditions based on the foregoing principles, and as each individual problem arises assign the highway in question to a given class. John A. Brodie, while Borough Engineer and Surveyor of Blackpool, England, divided the streets within his district into five classes, and determined the amount of traffic for which each class was suitable. His conclusions were as follows:

Class No. 1.—Foundation of Portland-cement concrete 7 inches thick covered with granite setts 5 inches to 6 inches in length, 3 inches in width, and 6 inches in depth; jointed with fine, dry gravel and boiling pitch and creosote oil.

This class is suitable for main suburban roads with traffic up to 200,000 tons per yard width of carriageway per annum; impervious to moisture; noisy, but clean; gradients up to 1 in 40.

Class No. 2.—Foundations of Portland-cement concrete 6 inches in depth, covered by specially selected Karri or Jarrah blocks 6 inches to 8 inches in length, 3 inches in width, 4½ inches in depth, laid close, direct on concrete, and grouted with boiling pitch and creosote oil.

Suitable for first-class shop streets, with traffic of about 100,-000 tons per yard width per annum; practically impervious, noiseless, clean, and dustless; gradients up to 1 in 40.

Class No. 3.—Foundations of hand-packed rubble 8 inches in depth, covered with 5 inches of tar-macadam.

Suitable for residential streets having a light traffic of 20,000 tons per yard width per annum; impervious, noiseless, clean, and dustless; gradients up to 1 in 24.

Class No. 4.—Foundations similar to No. 3, but 7 inches deep, with $2\frac{1}{2}$-inch gauge water-bound granite, to a finished depth of 5 inches, blinded with fine granite chippings.

Suitable for ordinary residential front streets with a light traffic of about 5,000 tons per yard width per annum; pervious, comparatively noiseless, dusty and sloppy; gradients up to 1 in 12.

Class No. 5.—Foundations similar to Nos. 3 and 4, 7 inches in depth, covered with Haslingden setts, 6 inches to 8 inches in length, 4 inches to 6 inches in width, and 6 inches in depth; jointed with dry gravel and boiling pitch and creosote oil; laid with a concave cross-section and channel in center.

Suitable for back (or secondary access) streets 9 feet to 18 feet in width, with a traffic of 60,000 tons per yard width per annum; impervious, clean, and dustless; very noisy; gradients up to 1 in 12.

It is not claimed that the preceding classified carriageway specifications are the best under all circumstances, but only that they are probably the most suitable for the author's district, and for use under similar conditions.

SPECIFICATIONS AND CONTRACTS

PRELIMINARY STEPS

ADVERTISEMENTS AND PROPOSALS

27. Introductory.—Before commencing the work of construction, it is necessary to prepare for the guidance of the constructor a set of specifications describing the character of the materials to be used and the manner in which the work is to be prosecuted. If the work is to be done by a contractor, a form of proposal and contract will have to be prepared. Typical forms of advertisement, proposal, contract, bond, and specifications are given in the following articles.

28. Advertisement.—

Office of County Commissioners of Nassau County

Sealed proposals for the improvement of the county road between Merrick and Bellmore, in Nassau County, addressed to the County Commissioners of Nassau County, N. Y., will be received up to 12 o'clock noon, April 15, 19...., at which time the proposals will be opened and read.

The work has been divided into four sections, as described and shown in the plans and specifications to be seen at the office of the County Commissioners at Merrick, and will be known as Sections 1, 2, 3, and 4, respectively.

Separate bids must be made for each section desired, but a single bid may be submitted for the whole work, if accompanied by bids for each section.

Bids for doing the work must be in accordance with the plans and specifications approved by the County Commissioners and on file at their office.

The County Commissioners of Nassau County expressly reserve the right to reject any or all bids.

Before the contract is awarded, the successful bidder or bidders will be required to furnish a bond of five thousand dollars ($5,000) for the faithful performance of the work in accordance with the aforesaid plans and specifications.

By Order of County Commissioners of Nassau County.

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29. Proposal.—

To The County Commissioners of Nassau County:

For the improvement as hereinafter specified of the section of the county road between Merrick and Bellmore, located in Nassau County, State of New York.

Made by Johnson and Holland.
Address: Jamaica, N. Y.

The undersigned hereby declare that they have carefully examined the annexed form of contract and specifications, and the drawings forming a part of the same, and have to their satisfaction examined the road on which improvement is proposed, and agree to furnish all tools, machinery, and other means of construction that may be necessary, and to do all the work and furnish all material as called for and in the manner provided by annexed contract, specifications, and drawings attached thereto, and requirements under them of the engineer, for the following prices, to wit:

1. *For excavations of all descriptions,* except ledge rock, including all grubbing, clearing, and incidental work, 50 cents per cubic yard.

2. *For ledge-rock excavation,* including all incidental work, $3 per cubic yard.

3. *For excavation for borrowed material* when outside the line of the road, including all incidental work not exceeding ½-mile haul, 60 cents per cubic yard.

4. *For shaping roadbed,* including all clearing, grubbing, forming of gutters, and all incidental work not requiring a change in the present grade of the roadbed of over 8 inches, 10 cents per square yard.

5. *For loosening and shaping present stone surface,* so as to form a proper cross-section, not including additional broken stone that may be required, 5 cents per square yard.

6. *For telford foundation in place,* including all materials and incidental work, 60 cents per square yard.

7. *For crushed stone in place,* including all materials, rolling, and incidental work, as provided for in the specifications, measured in the carts:

From Quarry A:

For 1st and 2d Sections, $1.00 per cubic yard.
For 3d and 4th Sections, $1.25 per cubic yard.

From Quarry B:

For 1st and 2d Sections, $1.30 per cubic yard.

For 3d and 4th Sections, $1.50 per cubic yard.

From Quarry C:

For 1st and 2d Sections, $1.50 per cubic yard.

For 3d and 4th Sections, $1.75 per cubic yard.

8. *For all vitrified drain pipe,* including all materials, excavations (except ledge rock), and incidental work:

24-inch pipe	$2.50 per foot
18-inch pipe	2.00 per foot
12-inch pipe	1.00 per foot
6-inch pipe	40 cents per foot

9. *For iron pipe,* including all materials, excavation (except ledge rock), and incidental work:

24-inch pipe	$4.85 per foot
18-inch pipe	3.25 per foot
12-inch pipe	1.95 per foot

10. *For cement rubble masonry,* including all materials and incidental work, $5 per cubic yard.

11. *For dry rubble masonry,* including all materials and incidental work, $3 per cubic yard.

12. *For extra work,* ordered in writing by the County Commissioners, including use of all tools, actual cost plus 10 per cent.

13. *For materials* furnished by contractor, actual cost as shown by paid vouchers.

14. *For laborers,* 15 cents per hour.

15. *For single team and driver,* 10-hour day, at county rates, plus 10 per cent.

16. *For double team and driver,* 10-hour day, at county rates, plus 10 per cent.

Accompanying this proposal is a certified check for $1,000, drawn on the Freeport National Bank, payable to the County Commissioners of Nassau County, which shall become the property of said Commissioners, should this proposal be accepted by said Commissioners and the undersigned fail to execute the contract with said Commissioners; otherwise, the check will be returned to the undersigned.

(SIGNED) *Name:* JOHNSON AND HOLLAND
Address: Jamaica, N. Y.

Date: April 15, 19...

CONTRACTS

30. Contract for Road Construction.—

CONTRACT

State of New York

County Commissioners of Nassau County

This contract for improving all the sections of the county road between Merrick and Bellmore, in Nassau County, made and concluded on the 20th day of April, 19. . . . between the County Commissioners of Nassau County, party of the first part, and William Johnson and James Holland, trading as Johnson and Holland, party of the second part.

Witnesseth: That, in consideration of the sums hereinafter mentioned to be paid by the party of the first part, and penalty expressed in the bond of even date with these presents and annexed hereto, the said party of the second part agrees with the said party of the first part, at their own proper cost and expense, to do all the work and furnish all materials necessary to improve the portions of the county road between Merrick and Bellmore, in Nassau County, in accordance with and as described in the specifications and plans attached hereto, and in full compliance with the terms of this agreement.

Plans, Profiles, and Specifications.—The plans, profiles, and specifications are hereby made a part of this contract, and will be held to cover any and all work that can reasonably be inferred as needed for a complete and workmanlike job. And it is understood that no advantage will be taken of discrepancies found in any drawing or specification.

If any doubt or dispute arises in regard to interpretation of the specifications, plans, or contract, the same shall be referred to the engineer, whose decision shall be final.

Changes in Plans.—The right is reserved to make such changes in the plans or specifications as may from time to time appear necessary or desirable, and such changes shall in no wise invalidate this contract. Should such changes be productive of increased cost to the contractors, a fair and equitable sum therefor, to be agreed on before such changed work shall have been begun, shall be added to the contract price, and in like manner deductions shall be made.

Contractors' Liability.—The contractors assume all risks and liabilities for accidents and damage that may accrue to persons and property during the prosecution of the work by reason of the negligence or carelessness of the contractors, their agents, or their employes.

Subletting Contract.—The contractors agree to give their personal attention to work embraced in this contract, and not to sublet the same or any portion without the written consent of the Commissioners.

Instructions to Foremen.—The superintendents or foremen of any particular portion of the work shall receive and obey the instructions of the engineer in case the contractors themselves are not present.

Work Begun and Completed.—The work is to be begun within 10 days after the execution of this contract and to be diligently prosecuted to completion in such order as may be prescribed by the Commissioners.

The contractors hereby agree to complete the work on or before October 15, 19...., which date may be postponed at the discretion of the Commissioners.

The County Commissioners hereby agree to close the road to travel, section by section, as the work progresses; but at no time will more than one section be closed unless the County Commissioners should so direct.

Laws and Ordinances.—The contractors and those under them shall conduct the work in such a manner as to fulfil all the requirements of state, county, or town laws and ordinances applying to the work in hand, and they shall take such necessary precautions as will guard against accident or loss of life.

Clearing Up.—The contractors are to leave the road in a neat condition, and to remove and clear up all rubbish and surplus material.

Incompetent and Disorderly Persons.—Should any person employed by the contractors appear incompetent or disorderly, he shall be immediately discharged on request of the engineer, and shall not be employed again on the work.

Definitions.—Where the word "Commissioners" is used in this contract, it shall be understood to mean the Board of County Commissioners for Nassau County, party of the first part to this contract, or their authorized representatives, limited by the particular duties intrusted to them.

Whenever the word "contractors" is used, it is understood to mean the persons that have entered into this contract as party of the second part, or their authorized representatives.

Whenever the word "engineer" is used, it is understood to mean the Highway Engineer of the County of Nassau, or his authorized representative.

Payments.—Payments will be made by the Commissioners to the contractors on work done under this contract as follows:

On monthly estimates furnished by the engineer, less 10 per cent. due on the said estimate; said 10 per cent. is to be retained until a section is completed, when all money due on that section will be paid on certificate

from the engineer that work on said section has been completed in accordance with the specifications.

Extra Work.—On receipt of written orders, signed by the County Commissioners, the contractors agree to do such extra work and furnish such materials as may be necessary for the same. The contractors shall receive the actual cost of all materials so furnished, as shown by paid vouchers, and for such labor and teams as are necessary, the price to be as herein agreed on.

In witness whereof, the parties hereto have set their hands, the date herein mentioned.

(Signed) Wm. A. Smith.
Fred C. Conway.
Robt. L. Russell.

County Commissioners, for County.
Johnson and Holland.
Contractors.

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31. Bond.—

Know All Men by These Presents:

That we, William Johnson and James Holland, as principals, and The National Surety Company, of Washington, D. C., as sureties, are held and firmly bound unto the County Commissioners of Nassau County, State of New York, in the sum of five thousand dollars ($5,000), to be paid to the said County Commissioners or their certain attorney, their successors, and assigns, for which payment well and truly to be made we bind ourselves, our heirs, executors, and administrators, jointly and severally, by these presents.

The condition of this obligation is such that, if the said principals, Johnson and Holland, shall well and truly keep and perform all the terms and conditions of the aforegoing contract for improving the county road between Merrick and Bellmore, in Nassau County, on their part to be kept and performed and shall indemnify the said County Commissioners of Nassau County as therein stipulated, then this obligation shall have no effect; otherwise, it shall remain in full force and virtue.

Sealed with our seals and dated this fifteenth day of April, 19....

(l. s.) William Johnson.
(l. s.) James Holland.
(l. s.) National Surety Company.

Witness:
F. A. Smith.

SPECIFICATIONS

32. Specifications for Road Construction.—

SPECIFICATIONS

. For improving the county road between Merrick and Bellmore, in Nassau County, beginning at a point near Main Street, Merrick, and extending to a point near Bellmore.

Approximate length of road to be improved, 5.47 miles.

Work to Be Done.—The contractors are to furnish all tools, machinery, and labor, and to do all the work in connection with the proposed improvement of said road (except as herein specified), including all grading, draining, and surfacing, in accordance with these specifications, and plans and requirements under them of the engineer. Said plans are to be signed by the County Commissioners of Nassau County and by the Highway Engineer of the said county, and form a part of these specifications. The contractor is to leave the road and immediate vicinity in a neat and presentable condition ready for use.

Estimated Quantities.—The following quantities of the work to be done are approximate only, and are intended principally to serve as a guide in figuring out the bids. The quantities may be subsequently increased or diminished, as may be deemed necessary by the County Commissioners of Nassau County, as hereinafter provided in the specifications.

Excavations (other than ledge)	3,000 cubic yards
Excavation, "borrowed material"	100 cubic yards
Ledge excavation	500 cubic yards
Rubble masonry	100 cubic yards
Rubble masonry laid in cement	200 cubic yards
Brick masonry	150 cubic yards
Vitrified clay pipe:	
24-inch pipe	200 linear feet
18-inch pipe	1,000 linear feet
12-inch pipe	500 linear feet
6-inch pipe	500 linear feet
Iron pipe:	
24-inch pipe	200 linear feet
18-inch pipe	200 linear feet
12-inch pipe	200 linear feet

Shaping roadbed, 30,000 square yards.

Loosening and shaping present stone surface, 2,000 square yards.

Telford foundation, 15,000 square yards.

Crushed stone, 5,000 cubic yards.

Earthwork.—The roadbed shall be graded for a width of 20 feet in conformity with the plans, profiles, and cross-sections that accompany and are a part of these specifications.

All materials excavated within the lines of the work and used for filling are to be paid for as excavations only. Materials used for filling brought from outside the lines of the work are to be paid for as "borrowed."

Embankments are to be made in layers not exceeding 12 inches in thickness, until the proper grade is reached.

All measurements for earthwork are to be made in excavation.

All surfaces and slopes are to be left smooth and neat.

Ledge-Rock Excavation.—Only boulders measuring over ½ cubic yard or ledge requiring blasting for its removal shall be classed as ledge rock; nor will allowance be made for ledge-rock excavation more than 6 inches below the subgrade.

Rubble Masonry.—Rubble masonry shall be composed of quarry stone free from structural defects and presenting good beds for material of this kind, and of suitable sizes and shapes for the work, so as to give a bond of at least 6 inches, and with sufficient headers to give well-bonded work, the larger stone to be used for foundation purposes.

Covering stone is not to be less than 12 inches thick, laid with close joints, and with the ends overlapping the side walls at least 12 inches.

Cement Rubble Masonry.—Cement masonry shall be used wherever directed by the engineer, and shall consist of sound stone with beds suitable for this class of work. The stone is to be laid in courses not less than 12 inches thick, with alternate headers and stretchers. The joints shall not be over 1 inch wide, and shall be well filled with cement mortar.

Cement mortar is to consist of one part natural cement and two parts clean sharp sand; or one part Portland cement and three parts clean sharp sand. The cement is to be kept, until used, in tight barrels or bags thoroughly protected from all moisture.

No mortar is to be used that has stood over 45 minutes or has taken an initial set or has been retempered.

Pipe Culverts.—The trenches are to be excavated to the grade shown on the plan and profile, and as given by the engineer, so as to insure a true alinement for the pipe.

Care must be taken that each section of the pipe has a firm bearing throughout its length.

All pipe must be sound and free from cracks and distortions.

No other allowance than the price per foot for laying pipes will be made for excavating the trench, except where the contractor is directed

to dig the trench more than 3 feet deep, allowance then being made for all material excavated beyond 3 feet.

Shaping the Roadbed.—In cuts and fills, unless specially directed, the roadbed is to be graded to a width of 20 feet, and is to be free from all spongy and vegetable matter, roots, and stumps. The roadbed prepared for the broken-stone surface is to be 12 feet wide, and brought to the grade and cross-section shown on the plans, and rolled with a steam roller until firm and hard. All depressions that may appear during the rolling are to be filled with earth and rolled until an even surface is obtained.

When no change from the present grade of those portions of the road not already surfaced with stone is shown on the profile, the roadbed is to be shaped to the proper cross-section and rolled to a firm, smooth surface, before the application of broken stone. The price for this work is to be included in that for shaping roadbed, and is to include all excavation and work that may be necessary for removing slight elevations and contiguous depressions, and also excavation for telford or macadam constructions that do not require a change in the present grade of the roadbed of over 8 inches. The width to be paid for in shaping the roadbed is to be only that covered by the broken stone.

Loosening and Shaping Present Stone Surface. Where deemed necessary by the engineer, the surface of those portions of the roadbed now covered with broken stone is to be loosened and given the proper cross-section; this class of work is to be paid for by the square yard. Should it be necessary after loosening the old roadbed to add more broken stone in order to form the proper cross-section, all extra stone so furnished will be paid for at the price agreed on for the character of the broken stone so used.

The price for loosening the present stone surface is to be allowed only when the present grade remains unchanged, and is not to be allowed on those sections of the road where the old bed is entirely removed in order to reach the proper grade. In this last instance, the only price allowed will be that for excavation.

Telford Foundation.—The telford foundation is to be used whenever directed by the engineer. The roadbed is to be first shaped and rolled as already described and stipulated. The stones for the foundation course shall be sound, with sharp corners, with a depth of 5 to 8 inches, width 3 to 6 inches, and length not exceeding 15 inches. They are to be laid lengthwise across the road, with the broad base down. Protruding corners shall be broken off, and the spaces filled with smaller pieces; the whole is to be rolled until firm. Should any depressions show, they shall be filled with stone and rolled until firm. The interstices must not be filled with earth. The thickness of the telford

foundation is to be 8 inches when finished. The price paid for the telford foundation is to include all work and materials necessary to do the work as above described.

Surfacing of Telford Foundation.—Broken stone varying in size from ¾ inch to 1½ inches is to be spread over the telford foundation so as to roll to a thickness of 4 inches, and shall consist of crushed trap rock, unless otherwise directed by the engineer. Broken stone is to be spread with forks from piles alongside the road or from a dumping board, or it may be spread directly from wagons specially constructed for this purpose; but in no case shall the stone be dumped directly on the foundation course, except that broken stone may be put directly on the roadbed from wagons if the pile of stone is continuous and in the center of the road. After spreading, the broken stone is to be rolled until firm and thoroughly compacted.

Finishing Course.—A surface of screenings, to consist either of trap-rock screenings or other binding material, as the engineer may direct, is to be applied in the same manner as specified for the finishing course for macadam construction.

Macadam Construction.—Macadam construction is to be used wherever directed by the engineer or provided for in the plans.

First Course.—The first course is to consist of sound stone broken to sizes varying from 1½ to 3 inches. The thickness of the first course after rolling is to be not less than 4 inches, and shall be thicker than this where specially ordered by the engineer. The broken stone is to be spread as already described for spreading the surfacing over a telford foundation. After spreading, the stone is to be rolled until firm and thoroughly compacted, and have a cross-section to conform to that shown by the drawings.

Second Course.—The second course shall consist of stones varying in size from ¾ inch to 1½ inches, and shall be crushed trap rock, unless otherwise ordered by the engineer. The thickness of the second course is to be 2 inches after rolling, and the manner of spreading is to be the same as provided for the first course. After spreading, it is to be rolled until the stones are firm and thoroughly compacted.

Third Course.—The third course shall consist of trap-rock screenings varying in size from dust to ¾ inch. The screenings are to be spread dry and be sufficient barely to fill the interstices, and shall be then swept in, watered, and rolled, after which from 1 inch to 1½ inches of additional screenings are to be spread dry, watered, and rolled until the surface becomes hard and smooth. In no case shall the screenings be rolled in dry. When specially directed by the engineer, other binding materials than trap-rock screenings may be used, but should be applied in the manner above described. Screenings should be dumped and spread in the manner specified for broken stone.

Resurfacing Portions of the Present Road Covered With Stone.—After bringing the present surface to the proper cross-section, as previously directed, it is to be covered with a layer of broken trap rock varying in size from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches, so as to roll to a thickness of not less than 3 inches, the broken stone to be applied before rolling the loosened stone of the old surface, unless the process of shaping up the old roadbed shall necessitate a thickness of more than 4 inches of loosened stone, in which case it shall be rolled before applying the top layer. The broken stone for the resurfacing is to be spread, rolled, and finished in the manner indicated for spreading the broken stone for macadam construction.

Rolling.—The rolling of the different courses of stone shall begin at either edge of the road and work toward the middle. Any special directions as to the manner of rolling, which may be given by the engineer in order to secure the best results, shall be strictly followed

GRADING

GRADING OPERATIONS

EXCAVATIONS, EMBANKMENTS, AND SUBGRADES

33. Classification.—Grading operations, as used in the construction of highways, may be classified under the headings: Excavation, embankment, and subgrade.

34. Excavation.—In excavating material in order that the cross-section of a highway shall conform to the desired lines and grades, the operations vary from the removal of a small amount of material, in surface grading, to excavations of many feet in depth. Excavation includes, in general, grading of the roadway, the ditches, and the side slopes. The excavated material is used to fill those parts of the highway that are below the proper grades. Surplus excavation is used in many cases to widen embankments and flatten side slopes.

35. Embankment.—Before construction of the embankment is begun, trees, large roots, brush, and other objectionable material within the entire area to be covered by the fill

should be removed. Where the filling is less than about 2 feet in depth, all vegetable matter should be removed from the original surface. These requirements are necessary in order to secure an embankment free from soft and spongy pockets. If stone filling is employed, the stones should not, in general, exceed a half cubic foot in size and the larger stones should be placed in the bottom of the embankment. No large stones should be used within 6 inches of the surface of the subgrade or shoulders. In the construction of embankments, it is of the utmost importance that the materials should be thoroughly compacted in order to avoid later settlement.

36. In order to secure thorough compacting, the material to form the embankment should be deposited in thin layers, not over 12 inches in depth, for the full width of the embankment and thoroughly compacted. The compaction is accomplished by machines and loaded wagons, used in grading operations, being drawn continually over the embankment and by rolling. Many engineers have obtained the best results by means of a steam roller, known as a puddling roller, which is provided with a grooved front wheel of the form shown in Fig. 4. Comparatively light rollers are used on thin layers of material. In the construction of highways on side hills it is advisable to stagger or roughen the material of the hillside, in order to form a mechanical bond between the material of the fill and the surface of the ground, thus guarding against the slipping of the embankment.

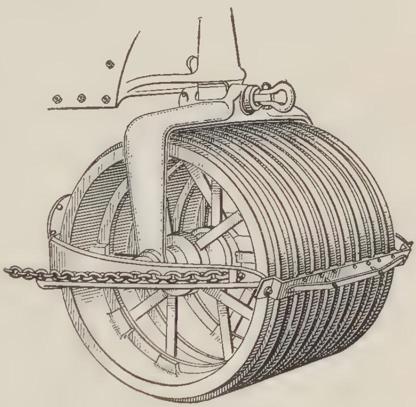

Fig. 4

When the excavated material suitable for use in the construction of an embankment is insufficient, additional material

is obtained from borrow pits or other sources. In cases where the haul of material required for embankment exceeds a given distance, the work entailed is classified as overhaul. If this distance is 2,000 feet, payment for overhaul would be based upon a rate per cubic yard for each 100 linear feet greater than 2,000 feet that the material is hauled.

37. Side Slopes.—For all practical purposes, earth, sand, and gravel, when used in either excavation or embankment, will be stable if the slopes are constructed with an inclination of 1 on 1½. On many roads, the slopes of the embankment and cuttings are protected from the washing effect of rain by a covering of grass sods, or grass seed is sown and properly cared for until the grass grows. When the slopes are exposed to the action of flowing water, as along the seashore or the bank of a river, they may be protected from injury by a dry stone paving or riprap.

38. Shrinkage of Materials.—It is important, in grading operations, to distinguish between loose measurement and measurement in place. Estimates are generally based on the yardage of material in place. It is a well-established fact that earth when removed from its original position in a bank increases in bulk or swells. It is also well known that when the excavated material is placed in a fill it will shrink and settle so that it will occupy a smaller space than it did originally. The swelling on removal from the original bank will vary generally from about 8 to 15 per cent., but in some cases may be as high as 40 to 50 per cent. The shrinkage is variable and depends upon the kind of earth, the manner in which embankment is made, and the climatic conditions.

39. Subgrade.—The subgrade consists of the upper surface of the native foundation on which is placed the artificial foundation. The subgrade is thoroughly compacted by rolling to conform to the lines and grades. All muck, quicksand, soft clay, or spongy material, which will not consolidate under the roller, is removed to such depth as is necessary and the space is refilled with suitable materials from excavations or with other

material, such as earth, gravel, or broken stone. All hollows and depressions that develop in rolling are filled with suitable material and the process of filling and rolling is repeated until no depressions develop.

GRADING MACHINERY

40. Classification.—Grading is accomplished by many different kinds of tools and machines. Among the most important are the following: Picks, shovels, plows, scrapers, wagons, drags, graders, rollers, and scarifiers.

PICKS, SHOVELS, PLOWS, AND SCRAPERS

41. Picks.—The pick may be pointed at both ends for ordinary excavation work in hard soils, or it may have one end flattened to a chisel point for use in trimming up slopes of cuts.

42. Shovels.—A pointed shovel with a short **D** handle is the one most commonly used in grading operations. Square-pointed shovels are adapted also for mixing either cement or bituminous concrete, and for handling sheet asphalt mixtures. Scoop shovels are used to advantage for handling sand or other fine material.

43. Mattocks, Bush Hooks, and Other Hand Tools. Mattocks, which are shaped like a pick, but with broad ends, are used mainly for trimming up slopes, for loosening soils full of roots, and around stumps. Bush hooks, a form of small hatchets, are used mainly in clearing away brush and small undergrowth. Hoes and rakes are principally used in shaping up the surface.

44. Plows.—As shown in Fig. 5, the essential parts of a grading plow are the beam *a*, the handles *b*, the share *c*, the mold board *d*, and the shoe *c*, which in some plows is replaced by a wheel. The beam is made either of wood or metal, the latter being preferable where a plow is to be continually exposed to the weather or is intended for use in stiff material. The share

and mold board are so made that the furrow may be turned either to the left or to the right. The function of the shoe c is to regulate the depth plowed. An ordinary grading plow of

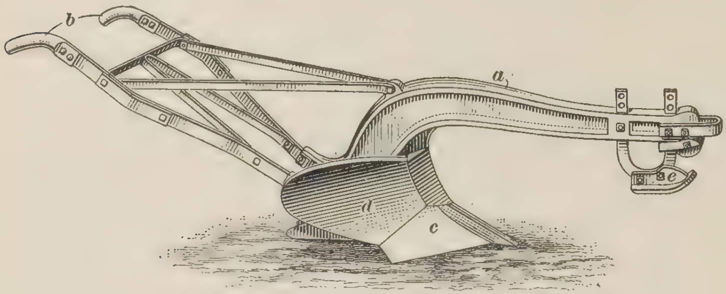

Fig. 5

the form shown in Fig. 5 weighs about 150 pounds and it plows a furrow about 10 inches wide and from 6 to 12 inches deep.

For breaking up hard-pan, old macadam, or other stiff material, a *rooter plow*, as illustrated in Fig. 6, is employed. This plow is generally made with an iron beam. A plow of this kind is best pulled by a steam roller or a tractor. If horses are used it may require from six to twelve, depending upon the material plowed.

45. Drag Scrapers.—A drag scraper, as shown in Fig. 7, consists of a pressed-steel bowl a to which a bail b and handles c are attached. Sometimes the bowl is reinforced with a double

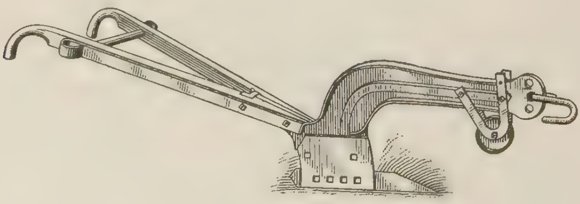

Fig. 6

bottom or with two pieces of strap iron which serve as runners. These scrapers weigh from 75 to 100 pounds, are made in several sizes, and generally are listed in catalogs to hold 3, 5,

and 7 cubic feet. These capacities, however, are figured on the basis of loose measurement and for a scraper heaped full. In actual work the size represented to hold 5 cubic feet will hold from 3 to 4 cubic feet. This form of scraper wears out very

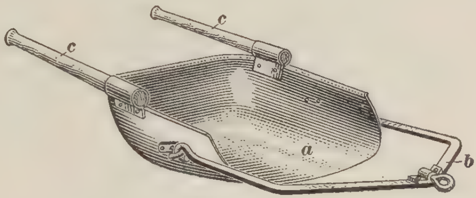

FIG. 7

rapidly on its cutting edge and on the bottom, particularly when working in hard-pan or gravel.

In operating a drag scraper, it is usually drawn by one or two horses. To load, a man grasps the handles and pushes the cutting edge down into the loosened earth as the scraper is pulled along. Then the full scraper is dragged along on its bottom to the point of dump, where either the driver or a dump

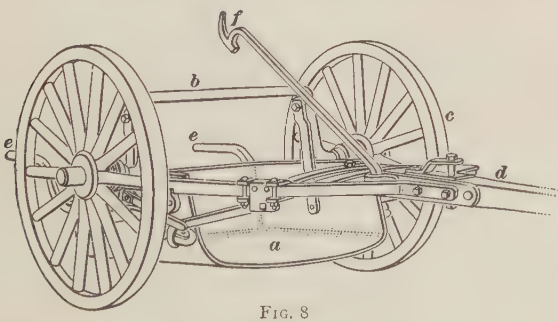

FIG. 8

man takes hold of one or both of the handles and lifts the scraper so that it turns upside down about its cutting edge.

46. Wheel Scrapers.—A wheel scraper, Fig. 8, is similar in shape to a drag scraper, but the bowl *a* is fixed to the axle *b* of the two wheels *c* to which is also fixed a pole *d*, as the scraper

is usually drawn by two horses. Wheel scrapers weigh from 400 to 700 pounds and are made in sizes of 9, 12, and 16 cubic feet capacity.

A wheel scraper is operated as follows: As it is pulled in its lowered position through the plowed material, a man grasps the small handles *c* at the rear of the bowl and tilts the bowl so that the cutting edge engages with the earth. When the scraper is full, he pulls down on the lever *f* and thus raises the bowl from the ground. The lever is locked by a catch and the scraper is hauled to the dump. To dump, a man pushes up on the lever *f*, which makes the cutting edge drop to the ground and causes the bowl to turn upside down about the axle. In some cases, during the process of loading the scraper, an extra pair of horses, called a snatch team, is attached to the pole in front of the team that drags the scraper. Small-size scrapers do not require a snatch team; medium-size scrapers usually do; and large-size ones always do.

47. Four-Wheel Scraper.—A four-wheel scraper, somewhat similar to the two-wheel scraper, is manufactured in a form in which the front and rear wheels do not track, thus serving to compact the fill during the process of grading. The capacity of the bowl is about 1 cubic yard, loose measurement.

The principle of operation is about the same as that of a two-wheel scraper, with the exception that the driver, who rides on the scraper, controls the levers that load and dump the scraper. The scraper is drawn by horses. Sometimes, however, such scrapers are used in trains drawn by a traction engine. It is claimed for this scraper that, if a traction engine is used, it is not necessary to plow except in the case of the most compact soils. In dumping the load, it spreads the materials in layers of any desired thickness.

48. Buck Scraper.—A type of scraper called the buck scraper, also known as a Fresno grader, is shown in Fig. 9. It consists of a bowl or scoop *a*, which is about 13 inches high, 18 inches wide, and from 3 to 5 feet in length. It weighs from 255 to 325 pounds, depending upon the size. Since the earth is pushed along in front of the bowl, the capacity will vary,

depending upon the material being moved and the size of the scraper. In any event it is more than the actual measurement of the bowl. For instance, the actual measurement of the bowl above described, 5 feet long, is about 8 cubic feet, but loads of about 19 cubic feet, loose measurement, have been drawn by this size scraper when working in a clayey earth.

The model here described is generally drawn by four horses and it loads and dumps in a similar manner to wheel and drag scrapers. When the load is dumped, the scraper rests on the

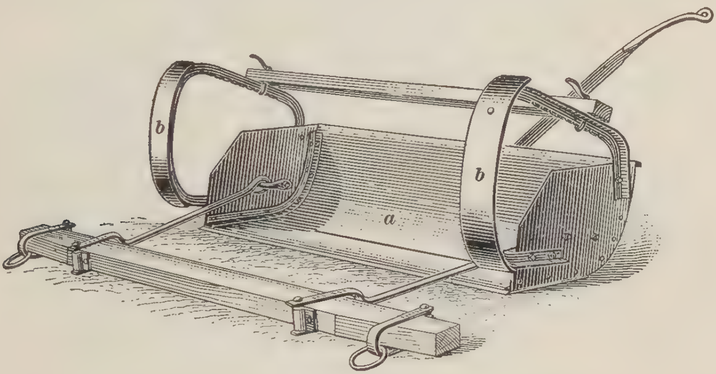

FIG. 9

runners *b*, which are fixed at either end, and is then dragged into position for reloading.

WHEELBARROWS, CARTS, AND WAGONS

49. Wheelbarrows.—Wheelbarrows are made either of wood, steel, or with a wooden frame and steel bowl. The wooden barrow possesses some advantages over one built with a steel bowl or all of steel. First, it is cheaper; second, it is more cheaply repaired and is much better adapted for quarry work, where a steel bowl is liable to be damaged by having stone thrown into it; third, it is somewhat lighter than either of the other two. On the other hand, if a semifluid material or a concrete or bituminous mixture is to be handled, a barrow with a steel bowl will serve the purpose much better. The weight of a

wooden wheelbarrow is about 60 pounds and of an all-steel barrow 75 to 80 pounds.

50. Carts and Wagons.—A one-horse tip cart is generally built with two wheels. To dump, the body tips over the axle, thus discharging its contents. The bodies, without side boards, have about 21 to 24 cubic feet of space.

Two-horse tip carts are operated on the same principle, but are built on four wheels. They hold about 1½ cubic yards of material, loose measurement. The front wheels are made small

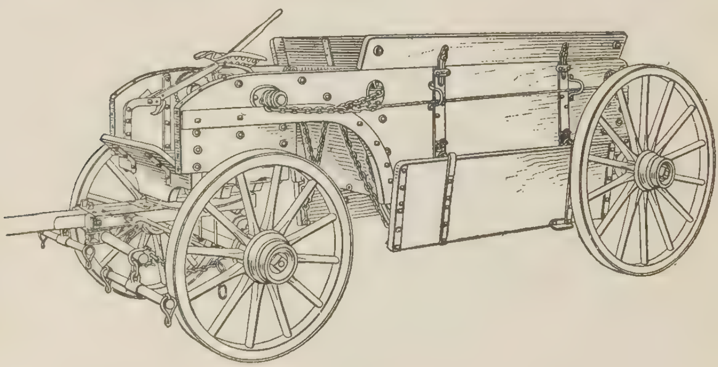

Fig. 10

so as to cut under the body and thus facilitate turning the cart around in a short space.

Slat-bottom dump wagons consist of a box fixed to a four-wheeled truck. The bottom is constructed of movable slats, generally made of 2″×6″ boards, which are removed one by one until the load is dumped. The only advantage of this type is that the wagon box may be cheaply replaced.

51. Patent-bottom dump wagons are made in 1, 1½, 2, 2½, and 3 cubic-yard sizes. The bottom of the wagon is made up generally of two leaves, hinged either to the side or to the ends of the box. Fig. 10 shows the first-mentioned type. These leaves, or doors, are held in place with chains which are wound up on a windlass operated by the driver. To dump the load, the driver, with his foot, kicks a release lever and the doors fall open, thus discharging the load. The doors are closed by

the driver turning the windlass. While the body of the wagon is generally made of wood, the bottom doors are sometimes made of wood and sometimes of sheet iron. One of the doors is usually provided with a lip that overlaps the joint formed by the doors and thus prevents material from sifting through. All types of these wagons are built to withstand extremely rough usage. They are not only suitable for grading work, but also are excellent for hauling stone, etc. The average weight of the wagon is about 2,000 pounds.

ROAD DRAGS, SCRAPERS, AND GRADERS

52. Road Drags.—One of the simplest and cheapest forms of road drags is the *split-log drag,* Fig. 11. It is a home-made tool, but is extremely useful in maintaining an earth road,

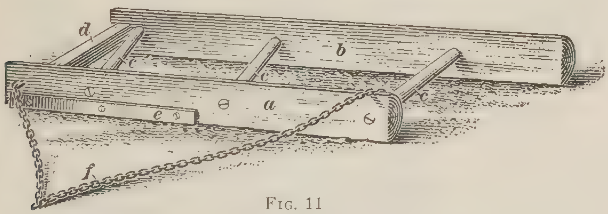

Fig. 11

and is today preferred by many to the steel drag. A dry red-cedar log is best, although red elm, walnut, box elder, soft maple, and willow make good drags when thoroughly dry. A log should be from 8 to 9 feet in length and from 10 to 12 inches in diameter. A wind in the log, provided it is not more than 4 inches in 8 feet, is not detrimental. The log is split as nearly in half as is possible, the heavier and better slab being used for the front log *a* and the other for the back log *b*. The logs are connected by braces *c* and an end brace *d* which runs from the center line of the log *b* to within 1 inch of the bottom of the log *a*. An iron strip *e* is fixed at the ditch end and projects ½ inch below the lower edge of the log at its outer end, but is flush with the lower side of the log at its other end. A platform of 1-inch boards, on which the driver stands, is placed over the cross-braces, the boards being fixed about 1 inch apart to allow any

dirt that comes onto the platform to sift through onto the road again. The chain *f* is put through the middle of the log at the ditch end and passed over the top of the log at its other end and fastened to a brace. This allows the dirt to pass underneath the chain as it runs from the ditch along the log to the middle of the road.

A plank-log drag is built in a similar manner to the split-log drag except that planks set on edge are used in place of the split logs, the planks used being 10 to 12 inches wide and 2 to 4 inches thick.

53. A lap-plank drag, shown in Fig. 12, is constructed of three planks *a* held together by iron brackets *b*. The planks

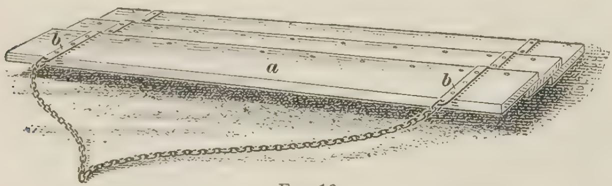

Fig. 12

being of small thickness, the edges can move only a small amount of material and the drag is therefore used mainly for smoothing up a road.

54. Adjustable Steel Road Drags.—Various forms of steel road drags are now manufactured that have the same over-all dimensions as the split-log drag, the logs or planks being replaced by angle irons or steel plates placed on edge. Their weight is considerably greater than that of split-log or plank drags and for that reason they are sometimes objectionable.

Steel drags are often equipped with a lever by which the blades can be tilted at any desirable angle. The drag shown in Fig. 13 is so equipped, the blades *a* being riveted to levers *b* pivoted to braces *c*. The levers *d* are connected by a double arm *e* which is attached to an adjusting lever *f* pivoted to the central brace *c*. By pressing the small lever *g* a pawl is lifted out of contact with the toothed sector *h*, thus allowing the lever and the blades to be tilted at the desired angle.

Some steel drags are made with three parallel blades instead of two and are provided with braces which, when the drag is turned upside down, serve as runners on which it may be drawn from point to point.

55. In operating a road drag, a team is hitched to the chain so that the drag will be pulled along the road, without a load, at an angle of about 45 degrees with the center line, the ditch end always being ahead. If it is desired to make the drag cut

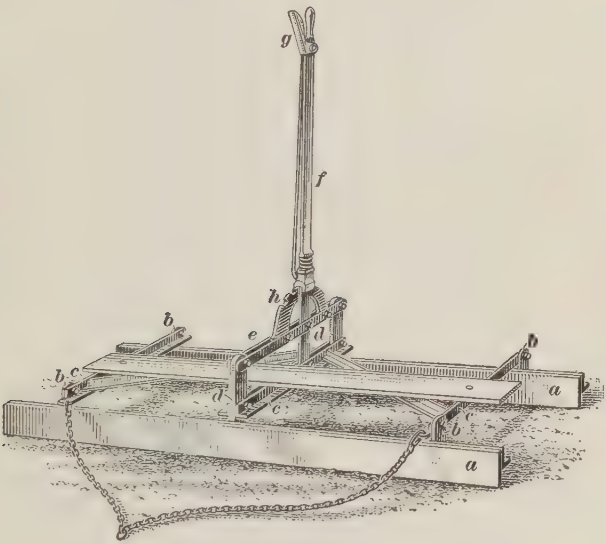

FIG. 13

deeper, the chain should be lengthened, as it is obvious that the nearer the team is to the drag, the greater is the tendency to lift it from the ground. The driver generally stands on the drag, when working, and by shifting his weight from one end to the other causes the drag to cut into the soil or to drop the soil that is carried along by it. To cut deep he shifts his weight mostly onto the front runner toward the ditching end; to cut light he shifts his weight toward the rear runner; to drop the earth carried along into a depression, he suddenly shifts his weight to the rear and toward the end of the drag nearest the

center of the road. Some of the steel drags are so heavy that they cannot be operated in this manner, and hence are not so adaptable to the work.

56. Road Scrapers or Graders.—There are several different types of road scrapers or road graders. The four-wheeled machine, Fig. 14, has blades from 7 to 8 feet long made up of two parts, a cutting edge *a* and a mold board *b*. The blade is suspended from a curved or a full circular frame *c* attached to the machine. By turning the large wheels *d*, which connect with a combination of worms, worm-wheels, and levers, the blades may be tilted at any desired angle with the vertical. By turning the handwheel *e* the pinion *f* will revolve the sector *g* and frame *h* together with the blade, thus enabling the latter to be adjusted into any angular position relative to the horizontal center line of the machine; in some machines the blade can be turned horizontally through a full horizontal circle. Such machines are generally called *reversible scrapers* or *graders*.

57. In some types of scrapers a forward or a backward tilt is given the blade by attachments fixed directly to it, while in others the blade is fixed in this respect, and the tilt is obtained by lowering or raising the front end of the frame over the front axle. It is also possible in some types to shift the blade sideways so that it projects beyond the wheels for some distance, which is a great convenience in filling in ditches or cutting down banks. The framework is generally made of steel shapes, although wood is sometimes used. Another feature of many of the four-wheel machines is that the rear axle is made telescopic so that either wheel may be shifted in a lateral direction, as shown in Fig. 14. This adjustment enables the rear wheels to straddle a furrow or to engage with the side of the bank and thus prevent side slip. In some makes the rear axle is pivoted so that it will turn through a small horizontal angle, helping the machine to keep in place when in the center of the road. There are some types also in which the rear wheels are so fixed to the axle that they may always be made perpendicular to the slope on which the machine is traveling. All of these different

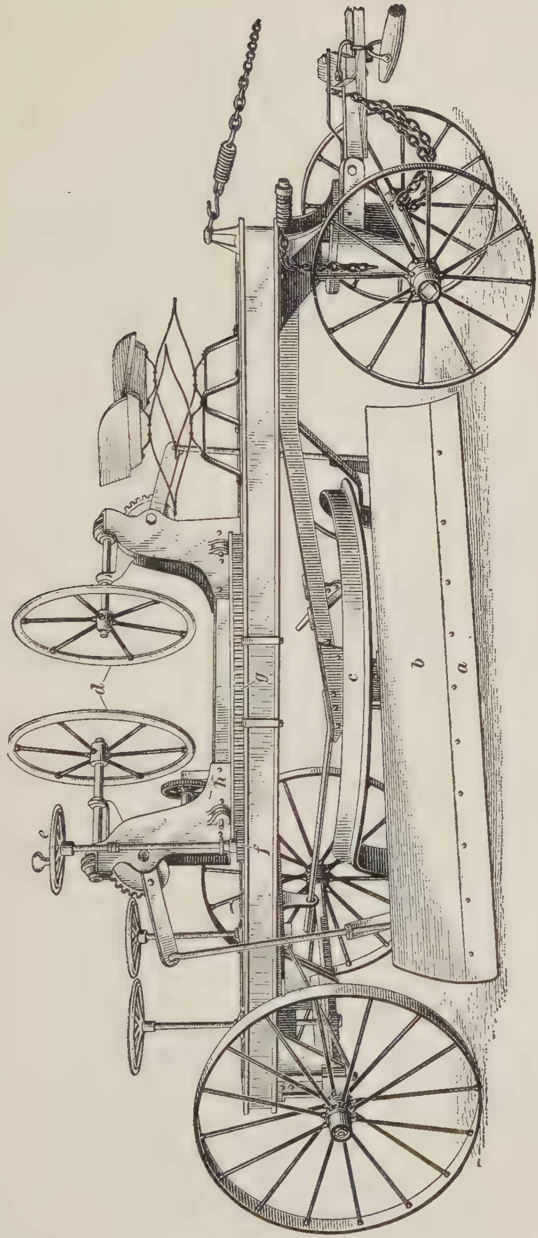

Fig. 14

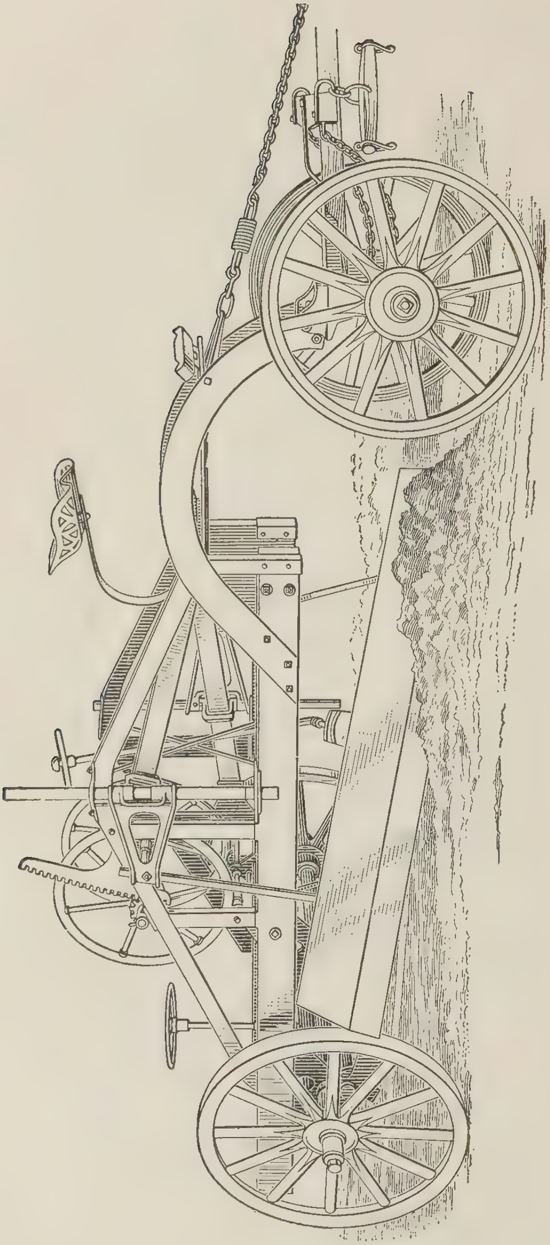

Fig. 15

adjustments are carried out by one man, who stands on the rear of the machine and operates the various wheels and levers which are within easy reach.

Various types of two-wheel scrapers are also manufactured. In these machines the blades are not so long as in the four-wheel type. The blades do not have the same ranges of movement as in the larger machines, and all the levers are worked by the man that drives the team. Flanges are usually provided on the wheels to prevent the machine from slipping sideways.

58. In constructing a road by means of a scraper, a cut is made at the edge of the ditch, using the point of the blade, the latter being set at a sharp angle so that only the point and a very short length of the blade come in contact with the ground, as shown in Fig. 15, which represents a machine differing in construction from that illustrated in Fig. 14. On the next round the blade is lowered to a flatter angle and the earth is moved along the blade toward the center of the road. By making several rounds of the scraper in this manner the road is crowned up at the center.

To smooth out the road, the surface is first thoroughly harrowed to break up large lumps, and then the scraper is drawn along the road with the blade set at right angles to the center line of the road. When a reversible machine is used the blade is turned around so that the convex side is ahead. A plow is not necessary in scraper work, since the machine can generally do all the plowing desired with the point of the blade. In order not to get a soft road it is not advisable to move the dirt up with the scraper in layers over 4 inches deep.

In some cases from one to three furrows are plowed at the ditch side of the road, the material being turned toward the center. The scraper is then set to work at the furrow nearest the center, and it moves over from this furrow toward the center only as much dirt as is loosened by the first round of the scraper. The next furrow is moved over in a similar manner, and the process is repeated until the last furrow is reached, which is moved over in turn. The road is then smoothed out.

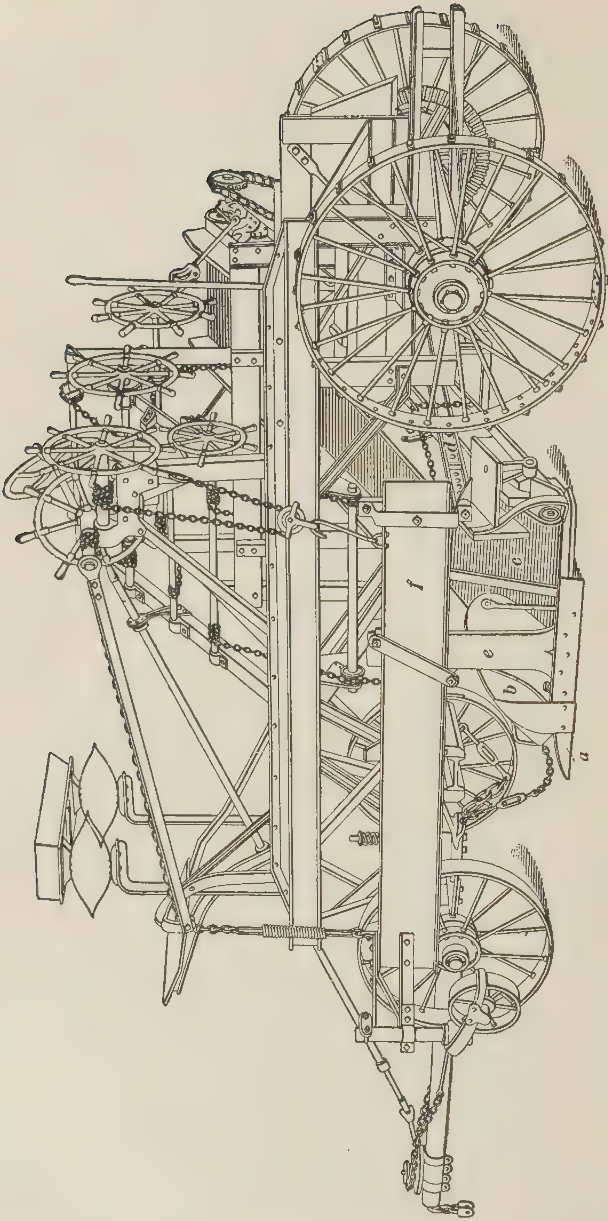

Fig. 16

The four-wheel machines for heavy work require from four to six horses, whereas two horses are used when the work is light. On the lighter two-wheel machines from two to four horses are necessary, depending upon the character of the work.

59. Elevating Graders.—The principal parts of the elevating grader shown in Fig. 16, are the plow *a* and the mold board *b*, the elevating belt *c*, and the trussed frame *d* by which the belt and plow are supported. In the type illustrated, the plow is pointed and is fastened to a bracket *e* carried by a heavy channel beam *f* at one side of the machine to counterbalance the weight of the elevating belt on the opposite side. A disk plow is sometimes substituted for the pointed plow. The mold board *b*, situated on the side and slightly to the rear of the plow, is shaped so as to deliver the furrowed material to the elevating belt with as little loss as possible. The grader, as it moves along, plows up the earth, which is thrown onto the elevating belt and discharged over its upper end either onto the road or into a wagon, which travels alongside the grader. The elevating belt is run either by gears driven by the wheels, as in this case, or by a gasoline engine set on the rear of the grader. When the carrier is driven by an engine, less power is required to haul the machine. The belt carriers are made in 3- to 5-foot sections, so that any length from 15 up to 30 feet in some of the larger machines can be obtained.

For heavy work, the grader requires twelve horses, two drivers, and two operators on the machine to operate the various levers controlling the movements of the plow and belt. A 25-horsepower traction engine may be used in place of the horses.

STEAM SHOVELS, ROLLERS, AND SCARIFIERS

60. Steam Shovels.—The portable revolving steam shovel, Fig. 17, has proved very efficient in highway grading operations. This type of steam shovel has been used for excavating earth, hard-pan, and small boulders. It may be used on cuts varying from 6 inches to many feet, and it is generally employed to excavate and load material into wagons.

61. Horse Rollers.—A horse roller is generally made with one large roller having a face of about 5 feet and a diameter of about 5 feet. Any weight desired from $2\frac{1}{2}$ to $5\frac{1}{2}$ tons, varying by 1 ton, can be obtained. Additional weight may be placed in the boxes at either end of the frame and the weight thus increased by 1 ton. The roller is made of steel or cast iron. An essential feature of a horse-drawn roller is to have it reversible, so that it can be drawn in either direction. In the roller shown in Fig. 18, the two-wheel truck may be uncoupled and

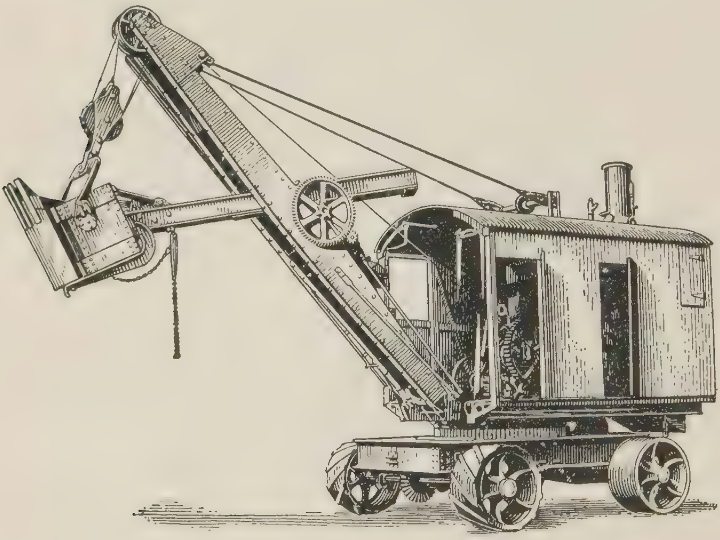

FIG. 17

attached to the opposite end of the roller. A grooved roller is sometimes specified, because with it better compression can be obtained than with the smooth-faced roller. The grooves are formed by bars bolted around the face of the roller parallel to the edges and at small intervals apart.

62. Three-Wheel Rollers.—Three-wheel rollers vary in weight from 10 to 20 tons. Most rollers of this type are run by steam, although there are a few makes that are run by gasoline engines. Fig. 19 shows a three-wheel steam roller. Rollers

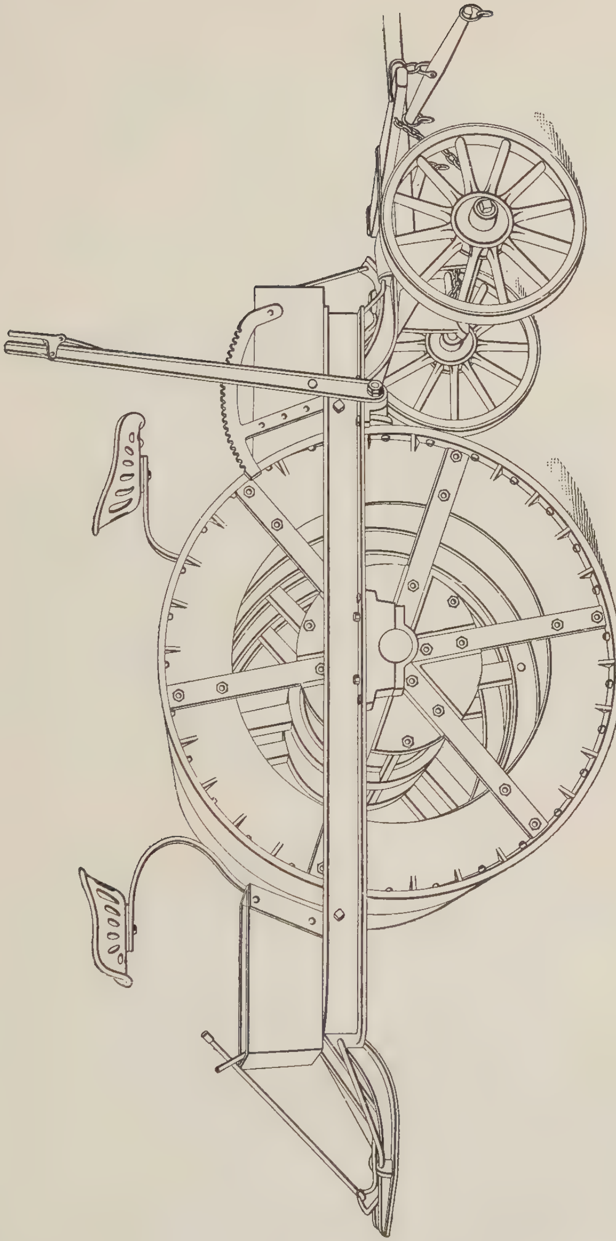

Fig. 18

are generally furnished with a high and a low speed. The low speed is used in rolling embankment, subgrade, telford, etc., while the high speed is used in finishing the surface or in traveling from point to point.

63. Tandem Rollers.—The weight of tandem rollers varies from 3 to 12 tons. These rollers are commonly run by

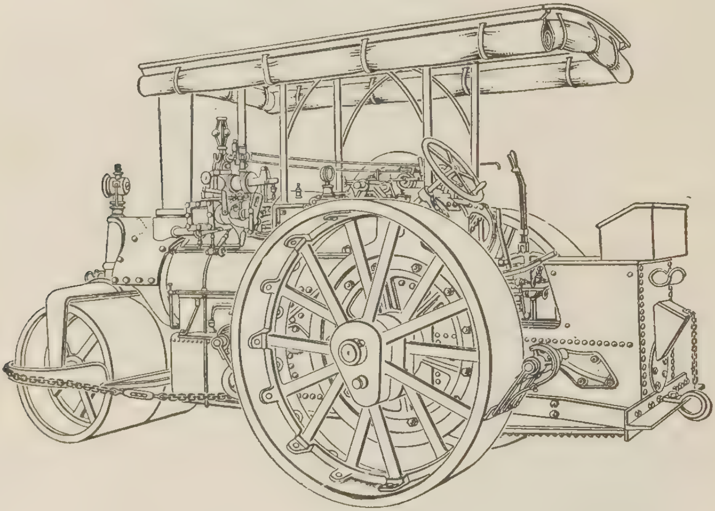

FIG. 19

steam (see Fig. 20) and are primarily used for the compaction of bituminous pavements.

64. Scarifiers.—A scarifier, Fig. 21, is a machine that serves the function of loosening a superficial layer of roadway surface. It consists of a heavy cast-iron block provided with a series of steel picks and supported on two or four wheels. The block weighs about 3 tons and the picks may be adjustably arranged in the block or the block itself arranged so that the pick can penetrate to any desired depth up to 5 or 6 inches. The picks are arranged in either a straight line or in two lines which, together, form a **V**. Most of the scarifiers are so designed that it is not necessary to turn them around. This is

accomplished, generally, by having two sets of picks, one set being used when the machine runs in one direction and the other

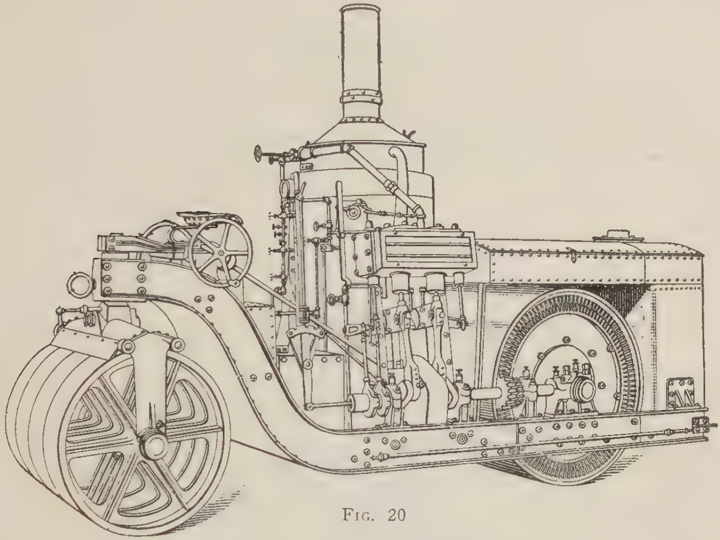

Fig. 20

when in the opposite direction. In operation, scarifiers of this type are towed by a chain hitched to a steam roller and the picks tear up the ground. The arrangement of the picks and the

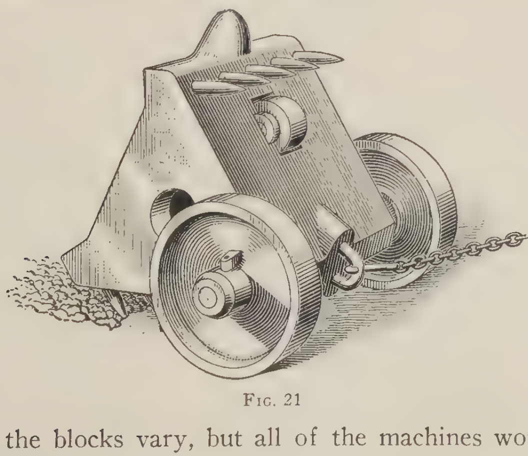

Fig. 21

form of the blocks vary, but all of the machines work on the same principle.

DRAINAGE

DRAINS AND DITCHES

ACTION OF DRAINS

65. Purpose of Drainage.—Water is one of the greatest enemies of roads. Through its solvent action, it softens and dissolves the materials of which the road is constructed, and by its expansion, while freezing, disrupts the roadbed by lifting and displacing its component parts. Hence, the speedy and efficient removal of water is imperative for the preservation of a road.

66. Drainage Systems.—Drainage may be either surface drainage or subsurface drainage, which is also known as subsoil drainage, or subdrainage.

Surface drainage provides for the removal of the rainwater from the surface of the roadway, and is necessary on all roads and pavements. *Subdrainage* provides for the removal of the underground water; it is required only under certain conditions and for certain kinds of soils.

Subdrainage is indispensable in those places where the roadway intercepts the natural drainage of the country. Much trouble and expense are caused by neglect of this important detail. A wet substratum cannot give a firm, unyielding subfoundation for a roadway, and such a stratum will invariably destroy the efficiency of the road under traffic. Where subsoil drainage is necessary, there should be no hesitancy in spending sufficient money to make it efficient, as this will save many dollars in the cost of maintenance.

67. Effect of Soils and Rock on Drainage.—The sandy soils, unless saturated with water, do not present any

difficulty in securing a dry and solid subfoundation, especially if the fall of the natural drainage is away from the line of the road, in which case gutters and side ditches for the removal of the rainwater will generally be found sufficient. The clay soils naturally retain water, although they are not readily saturated. When they reach the state of saturation they become very unstable and are incapable of supporting heavy loads; it is, therefore, necessary to provide a suitable system of subsoil drainage for them.

Rock requires little attention to drainage, except where the strata are interspersed with seams of clay or openings and are inclined toward the roadway, in which case means must be provided for the removal of the water in order to prevent slips.

68. Subdrainage.—The removal of the subsoil water is effected by constructing underground drains or deep side ditches

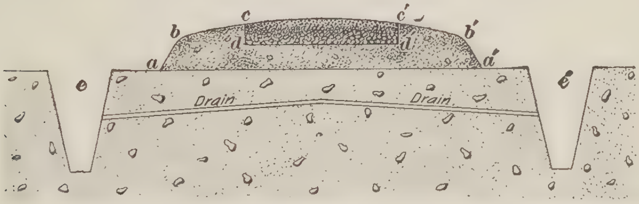

Fig. 22

that discharge into the natural streams. The surface water is removed by gutters connected with the side ditches or underground drains. The manner of arranging and constructing the drains and ditches is explained in subsequent articles.

Where the road is in embankment, the underground water will not reach the roadbed, and the drains required will be usually for the purpose only of providing a free passage for the surface water from the adjacent land. The size of the drains must be ample to accomplish this; otherwise, the embankment will become a dam, and consequently be liable to damage in time of heavy rain.

In marshy localities, it may be necessary to drain the ground on which the embankment is to be formed. This is usually effected by side and transverse drains, as shown in Fig. 22, in

which e and e' are the side ditches; $a\ b\ c\ c'\ b'\ a'$ is the embankment; and $c\ c'\ d'\ d$ is the roadway.

69. In some cuttings, catch-water drains (that is, small ditches) should be made along the top of the uphill bank, to receive the surface water from the higher land and prevent it from washing the slope. These small ditches either discharge into the natural watercourses or are carried down the slope in paved channels and empty into the side ditches.

DRAIN CONSTRUCTION

70. Requirements in Construction of Drains.—The following requirements must be complied with in the construction of drains:

1. *The Area of the Drain.*—The area of cross-section of the drain should be in proportion to the amount of water to be removed. For tile drains, 4 inches should be the minimum size.
2. *The Filling.*—In filling the trenches, care must be taken that the material used does not choke or stop the waterway.
3. *The Materials.*—Only durable materials should be employed, as the cleaning or repairing of a drain involves a great deal of expense.
4. *The Depth.*—The drains should be placed at a sufficient depth to accomplish the object sought, and always below the frost line. A deep drain will be more effective than a shallow one.
5. *The Inlet and Outlet.*—The ends of the drain should be such as to allow free passage of the water, and should be well protected.

71. Arrangement of Subsoil Drains.—The manner of arranging the subsoil drain depends entirely on the condition of the soil, the nature of the underflow, and the topographical conditions. In a flat country, where the soil is naturally wet and there is no flow to the underground water, it is considered good practice to use two lines of drains, one on each side of the road, as shown in Fig. 23; these discharge into the natural watercourses that cross the road. If the amount of water is

so great that the two lines of drains may prove ineffective, they may be supplemented by **diagonal drains** (shown by the dotted lines in Fig. 23) placed across the road about every 15

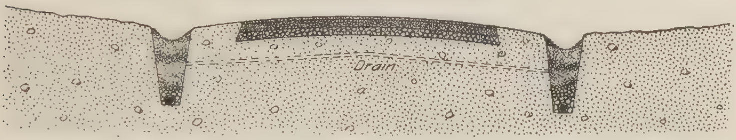

Fig. 23

feet, and discharging into the longitudinal drains. The longitudinal drains may sometimes be omitted, and the diagonal drains allowed to empty directly into the side ditches.

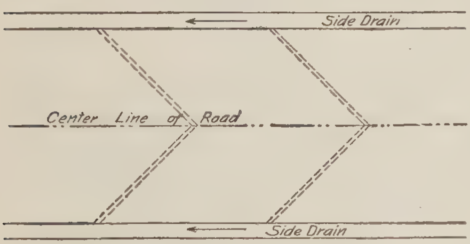

Fig. 24

The diagonal drains are placed in a **V** form, as shown in Fig. 24, with the point, or vertex, at the uphill end and in the center of the road. The distance apart at which these drains should be placed must be determined by the nature of the soil and the amount of water. It is generally considered that the

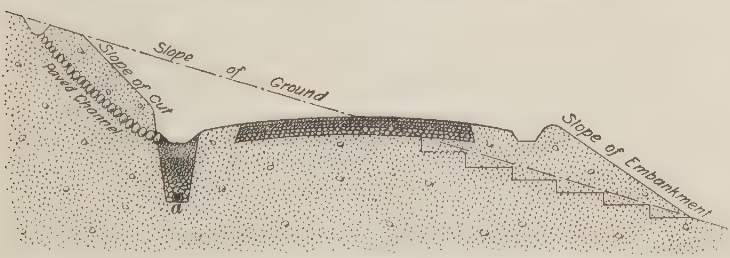

Fig. 25

action of an underground drain will not extend beyond 30 feet in sand or gravel nor beyond 15 feet in clay.

In cases where there is a well-defined flow from one side of the road to the other, as in roads located on hillsides, one longi-

tudinal drain placed so as to intercept the flow may be sufficient; such a drain is shown at *a*, Fig. 25.

It is sometimes recommended that a single drain be run through the center of the roadway. This location is not advisable; in the case of a break or stoppage, it is expensive to repair or clean out, and traffic will be interrupted. Besides, in the rolling of the road with heavy steam rollers, the drain is liable to be broken.

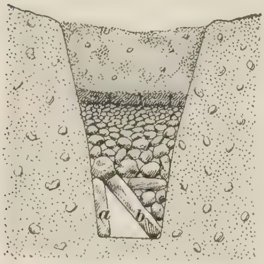

FIG. 26

72. Box Drains.—Where stone is abundant or can be procured cheaply, it is employed in the construction of drains in the manner shown in Fig. 26. The drain may be formed by first digging a trench about 2 feet wide, to the depth required to secure the proper fall or grade; the bottom is carefully graded to a uniform slope, and then large flat stones *a* and *b* are placed to form a triangular passage for the water. The ditch is filled to about one-half its depth with field stones of various sizes, the smaller sizes being placed on top; on the stones is placed a layer of sod with the grass side down; if sod cannot be procured, hay or fine brush may be used instead. The ditch is then filled with earth. This form of drain is called a box drain.

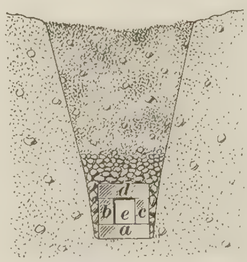

FIG. 27

Box drains can be made with bricks instead of stones, as shown in Fig. 27. Bricks *a, b, c, d* are placed in the bottom of the trench in the positions shown, so as to form a channel *e* for the water; the trench is then filled with earth.

73. Gravel Drains.—Where gravel abounds, the larger pebbles are used to form a drain in the manner shown in Fig. 28. In this type of drain, the ditch is excavated as just described, and filled with gravel to a depth of 1 foot

or more, the largest stones being placed at the bottom, and the smallest stones at the top. The gravel is covered with sod, hay, or brush, and the trench is then filled to the top with earth.

74. Pipe Drains.—One of the best and cheapest methods of providing for subdrainage is by means of lines of tile pipe, made of either cement or vitrified clay. The cement pipes are generally made with plain ends and the vitrified pipes with bell and spigot ends. The pipes are made in 1-foot lengths for small diameters and in 2-foot lengths for large diameters.

The required size of pipe depends on the amount of water to be carried and the grade to which the pipe is laid. There are several formulas by means of which the size can be determined.

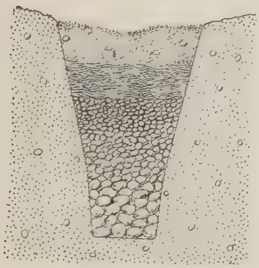

Fig. 28

The assumptions that must be made, however, in applying a formula to any particular case are such as to render an accurate determination of the proper size impossible. For instance, the amount of water to be carried off cannot be more than roughly approximated, and very little reliable data relative to the flow of water in pipes of this kind are obtainable. The amount of water is generally assumed to vary between $\frac{1}{4}$ inch and 1 inch per acre per 24 hours on the area to be drained, an average value being about $\frac{1}{2}$ inch. Experience as to what a tile drain has accomplished in any particular locality is a better guide than any result that may be obtained by formula. It has been well established in practice that the minimum size of drain should be 4 to 5 inches.

75. In places where no drains have been laid, the size of pipe obtained by formulas may serve as a guide in judging of the proper size to be used. A formula of this kind is the following, given by Professor I. O. Baker:

$$A = 1.9\sqrt{\frac{f\,d^5}{L}}, \qquad (1)$$

in which A is the number of acres for which a tile pipe having a diameter of d inches and a fall of f feet in a length of L feet will remove 1 inch in depth of water in 24 hours. Solving for d,

$$d = .77\sqrt[5]{\frac{LA^2}{f}} \qquad (2)$$

EXAMPLE.—From an area of 14 acres, water sufficient to cover it to a depth of 1 inch is to be drained every 24 hours through a tile drain having a fall of 27 inches in 300 feet. What size of pipe will be required?

SOLUTION.—In this case $A=14$ acres, $f=27$ in.$=2.25$ ft., and $L=300$ ft. These values being substituted in formula **2**,

$$d = .77\sqrt[5]{\frac{300 \times 14^2}{2.25}} = 6 \text{ in., nearly.} \quad \text{Ans.}$$

76. The tile pipe is usually laid at the sides of the road along the lines of the open ditches and at a depth of 2½ to 3 feet below the bottom of the ditch. On streets that are paved and curbed, the pipe is frequently laid underneath the gutters or curbs. After the pipe is laid the trench is filled with broken stone, gravel, earth, brush, or combinations of these materials, in the manner shown in Fig. 29. In this figure, a represents the tile; b c d e the stone or gravel filling; and d e f g the earth filling. The tiles are laid end to end, and are held in place by stones placed underneath and at the sides. The joints are left partly open to permit the free entry of the water.

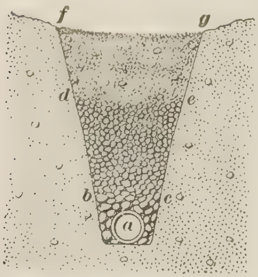

FIG. 29

In clayey soils a tile pipe will drain on each side a width of about six times its depth below the surface; in porous soils the distance drained on each side may be as much as fifteen to twenty times its depth below the surface. The minimum grade, as specified by some engineers, is 6 inches in 100 feet. All drains must be carried to a proper outlet, such as a culvert, ditch, or another drain.

77. The tile drains constructed by the Massachusetts and the Maryland Commissions are laid as follows: First, 2 inches of broken stone or gravel that will pass through a $1\frac{1}{4}$-inch screen and not through a $\frac{1}{2}$-inch screen is used for a bed; the joints are left open; clean gravel or broken stone of the same size as that used for the bed is filled about the pipe and over it for a depth of 1 foot. The remainder of the trench is filled with stone that will pass through a 3-inch and not through a 1-inch screen. This construction corresponds, in general, with that shown in Fig. 29.

DITCHES

78. Dimensions and Grade of Side Ditches.—The object of side ditches is to carry away the surface water, and sometimes the subsoil water. When not intended to remove the subsoil water, they need not be in depth more than from 1 to 2 feet, and in width more than 3 to 6 feet. When the ditch is required to carry the subsoil water, its depth and width will be controlled by the nature of the soil, the position of the outlet, and the amount of water to be carried.

The sides of the ditches should be formed with slopes not steeper than 1 vertical to $1\frac{1}{2}$ horizontal, and, if the conditions will permit, flatter slopes may be employed. The grade should have a uniform fall to the outlet. If the slope is very steep, it may be necessary to pave the bottom of the ditch with stones to protect it from injury in time of heavy rainfalls. The alinement should be as nearly straight as possible; where angles occur, they should be rounded off with a curve of as large a radius as practicable.

As deep side ditches are both dangerous and expensive to maintain, it is advisable in some cases to construct a stone or a tile drain at the depth required, refill with stones or earth, and form a shallow ditch on the surface, with inlets for the surface water at suitable intervals. This form of construction is shown in Fig. 30.

79. Cross-Sections of Ditches.—On roads it is usually necessary to construct ditches only in cuts, since on fills the

grade of the roadway is raised above the general ground level. When the fills are shallow or the road has a steep grade, the construction of gutters may be advisable to protect the shoulder

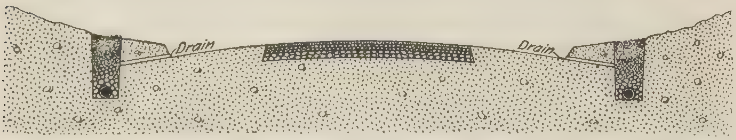

Fig. 30

of the road. The ditch or gutter usually has the same grade as that of the center of the road, although on very flat grades the ditch may have a steeper grade than the roadway.

The cross-section of the ditch is usually made in one of the following forms: the **V**-shaped, the trapezoidal, and the wide, flat ditch. The latter type is, in reality, formed by a continuation of the slope of the roadway surface. A ditch having a trapezoidal or a **V**-shaped cross-section will carry more water,

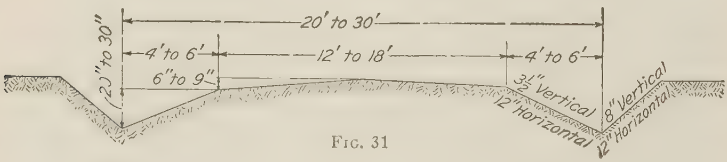

Fig. 31

but is much more liable to gully out than one constructed wide and flat. Other advantages of the wide and flat ditch are that it is not so dangerous to the traffic and that it is much easier to construct and maintain, particularly if a road grader is used in doing the work. The width and depth of the ditch depend upon the amount of water to be carried, and vary to some extent with the width of the road. Typical **V**-shaped, trapezoidal, and wide and flat ditch sections are shown in Figs. 31, 32, and 33, respectively.

80. Length of Ditches.—Water should not be carried over too long a distance in a ditch before it is given an outlet, since the amount of water will become so great that the capacity

of the ditch will be exceeded, and gullying will result. It is also easier to turn off a small amount of water into adjacent fields without objection on the part of the property owner, than it is to dispose of a large amount in this manner. There are places along the road where the water may be turned off at each side,

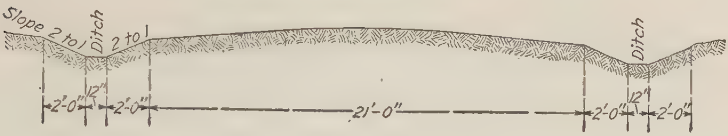

FIG. 32

such places, for instance, as fills with the ground sloping away from the road on both sides. If there is much water to be turned over a bank in this manner it will be necessary to protect the bank from washing out. A small amount of water running down high banks composed of sandy soil is liable to cause great damage, for the small gullies made by the water may rapidly extend back into the roadway surface. The bank should be protected by sod, or a paved gutter should be built down the side of the bank to carry the water. On hills where the grade

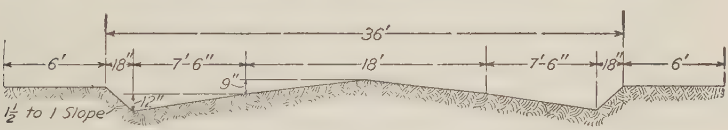

FIG. 33

exceeds 3 per cent. and the soil is loose and sandy, it may be necessary to pave the ditch with cobblestone, field stone, brick, or paving blocks in order to prevent gullying.

81. Water Breaks.—On steep grades, it is the practice in some localities to build water breaks (mounds of earth or stone varying in height from 6 inches to 2 feet) diagonally across the surface of the road, to turn the water that runs down the surface of the road into the side ditches. On an improved road, they have no place and should not be used, as they are an inconvenience and a danger to travel. The surface of the road should be crowned enough to throw the surface water into the side ditches.

FOUNDATIONS

NATURAL AND ARTIFICIAL FOUNDATIONS

82. General Considerations.—The soil composing the subgrade or natural foundation, eventually supports the weight of traffic coming on the wearing course of the roadway. Usually the soil does not possess sufficient bearing power to support adequately the wearing course and the traffic that comes upon it. It is necessary, therefore, to utilize an artificial foundation in order to distribute the traffic loads on a larger area of the subgrade. Thus traffic loads are, under average conditions, transmitted through the wearing course of the roadway to the artificial foundation, and thence to the natural foundation or subgrade of the highway. It is thus seen that as the traffic loads increase with a given kind of soil or as the supporting power of the natural foundation decreases, the strength or thickness of the artificial foundation must be increased. With the exception of earth and sand-clay roads, the construction of all of the more common types of roads and pavements might be described as composed of three distinct steps: (1) The construction of the subgrade or natural foundation, (2) the construction of an artificial foundation, and (3) the construction of the wearing course or pavement. On this assumption, therefore, the lower courses of either a broken-stone or of a gravel road will be considered as types of artificial foundations.

NATURAL FOUNDATIONS

83. Classification.—The natural foundation is composed of rock, gravel, or some kind of soil. Soil is defined as a mixture of fine earthy material with more or less organic matter resulting from the growth and decomposition of vegetation or

animal matter. The common soils encountered in highway work are classified as follows: Sand, clay, loam, marl, peat, and muck. The distinguishing physical characteristics of these soils are as follows:

Sand is composed of finely divided particles of disintegrated rock.

Clay is finely divided earth, which is mainly formed by the decomposition of feldspar and micaceous rocks. When wet, it becomes very plastic and is extremely unstable, and, due to its impermeable qualities, it dries out slowly. A clay becomes hard in drying and contracts to such an extent that areas, where large clay deposits occur, are traversed by wide cracks.

Shale is of the same composition as clay but has a laminated structure and is similar in appearance to slates. Shale will rapidly disintegrate on exposure to the atmosphere.

Loam may be any soil combination of sand and clay, as it contains more or less of each of these materials. In the Middle West a black loam which contains so much clay as to be sticky when wet is known as *gumbo*.

Marl is a term that is applied to all calcareous clays containing a minimum of 15 per cent. of carbonate of lime and a maximum of 75 per cent. of clay. The larger the proportion of carbonate of lime, the less plastic is the material, until finally it is no longer considered as marl, but is called argillaceous limestone.

Peat and *muck* are generally distinguished from other soils by the presence of humus or vegetable matter. Peat is formed by the decomposition of vegetable matter under water.

84. Improving Natural Foundations.—Gravel, clay, and sand make excellent foundations if well drained. A clayey subsoil may be improved by the addition of sand or gravel, while a sandy subsoil may be improved and made more unyielding by the addition of clay. Muck should be removed for a certain depth, varying with local conditions, and replaced with some other material. The availability of materials will usually determine which of the following should be used for adding to or replacing the unsatisfactory soil: Broken stone, stone screenings,

gravel, sand, shells, cinders, clinkers, brickbats, slag, or clay. Any subsoil will generally be improved by rolling, and such a process will show up weak spots, which should be replaced with other material.

ARTIFICIAL FOUNDATIONS

85. Available Materials.—Artificial foundations are usually constructed of large stone, gravel, broken stone, slag, hydraulic cement-concrete, or bituminous concrete. Brush and plank have been employed in the construction of foundations through swampy land. Old pavements have frequently been made to serve as foundations for surfaces of some other type. The selection of any particular type is governed principally by

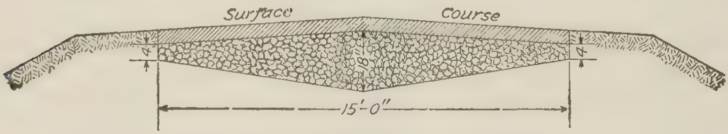

FIG. 34

considerations of the type of roadway surface to be supported, the traffic to which the surface is subjected, relative cost of available materials, and the natural soil conditions.

86. Telford Foundation.—The artificial foundation known as telford foundation, because advocated by Thomas Telford (1757-1820), is usually constructed on a subgrade, the surface of which is parallel to the finished surface of the road. The stones used vary from 3 to 8 inches in width, 6 to 15 inches in length, and from 6 to 8 inches in depth. The stones are carefully laid on the subgrade with the greatest length across the road, and the widest edge down. The projecting edges of the stones above the surface are knocked off with a hammer, and the spaces between the stones are packed and wedged with spalls, or chips. After the whole surface is rolled with a heavy roller it is ready to receive the upper courses of stone.

87. V Drain Foundation.—A V drain foundation, Fig. 34, is constructed by excavating the roadway for its full

width, from 4 to 8 inches deep at the sides and from 12 to 18 inches deep at the center, thus producing a flattened **V**-shaped trench. This type of construction serves as a drain as well as a foundation. The excavated space is filled with boulders and small stones. The larger stones are placed at the bottom of the trench and the smaller stones at the top. The trench is intercepted by drains, constructed across the road at the low points, which take away the water that flows through the **V** drain.

88. Broken-Stone Foundation.—In a broken-stone foundation, the lower, or bottom, course of a broken-stone road, when the foundation is built in two courses, is the foundation for the upper or wearing course. It is usually about 4 inches in depth after compaction, but should be as much as 6 to 8 inches deep in order to take the increased loads due to modern traffic. Where the subsoil is unstable or the road is subjected to very heavy traffic, or where it is desired to aid the subdrainage of the road, the lower course should be increased in thickness or an additional course of broken stone should be used. This extra layer, sometimes called the subbottom course, varies from 3 to 18 inches in thickness and is composed of the largest sized products of the crusher or of large field stone, broken boulders, or ledge stone. Gravel, slag, brickbats, cinders, or clinkers are often substituted for the broken stone in foundation courses.

89. Cement-Concrete Foundations.—Concrete foundations should ordinarily be used under all types of stone-block, brick, wood-block, sheet-asphalt, and bituminous-concrete pavements.

Concrete is a mixture of water, hydraulic cement, sand or other fine material, and broken stone or gravel or similar material. The best and strongest concrete will result when the sand is sufficient in quantity to just fill the voids in the stone, and enough cement is used to fill the voids in the sand and stone. An accurate proportioning of the materials can be made only by carefully determining the voids of the various ingredients; and since the sand, stone, and gravel are quite variable in this respect, frequent determinations should be made. It is customary in practice to adopt certain definite proportions such as

1 : 2 : 5, 1 : 3 : 6, or 1 : $2\frac{1}{2}$: 7; the first figure indicates the number of parts of cement, the second figure, the parts of sand or fine aggregate, and the third, the parts of the coarse aggregate.

90. Two kinds of cement are used, Portland and natural, and there are many brands of each. A natural cement does not produce so strong a concrete and it obtains its initial set much quicker than a Portland cement. On this account, and because the two cements are nearly equal in price, Portland cement is usually specified to be used in all classes of concrete foundations.

The thickness of the concrete foundations commonly used varies from 4 to 8 inches, 6-inch thickness usually being employed. An 8-inch foundation is necessary only when the subsoil is extremely unstable or the traffic exceptionally heavy. Whenever a concrete foundation is constructed, traffic should be kept off it for 7 to 10 days in order to allow it to set thoroughly.

91. Bituminous-Concrete Foundation. — A bituminous-concrete foundation is used to some extent as a substitute for a hydraulic cement-concrete foundation for sheet-asphalt and bituminous-concrete pavements.

HIGHWAYS

(PART 3)

MATERIALS OF CONSTRUCTION

NON-BITUMINOUS MATERIALS

SAND, GRAVEL, AND BROKEN STONE

1. Sand.—The sand used for paving purposes should be clean and preferably silicious. It should be free from loam and clay, and it should be sharp; that is, the grains should be angular in form, and not rounded.

2. Gravel.—Gravel to make a good road material should be composed of stones that are hard and tough, and, hence, will not readily disintegrate under traffic. The stones should vary from large to small size, the proportions of the different sizes being such that the voids will be as few and small as possible, and enough binding material should be present to cement the whole mass together. Gravel composed of sharp, angular stones, with slightly roughened surfaces, has given particularly satisfactory results. Clay, iron oxide, lime, loam, and finely divided silica constitute the cementing mediums found in gravels. Usually an excess of 15 per cent. of clay in the mass will produce mud during a continued wet

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spell; 10 to 15 per cent. of clay is sufficient to bind well-graded gravel.

As a general rule, bank gravel is better than stream gravel because its particles are not generally so smooth, and because it contains more fine material that will act as a binder. River gravel contains more silica than bank gravel of the same locality, since the clay has probably been washed out. Gravel that contains too much fine material may be improved by screening, while gravel that is lacking in binding material can be improved by adding some cementing material, such as clay, shale, marl, loam, or stone screenings. An indication of the binding qualities of a gravel may be obtained by examining the gravel in the bank. Usually, if the bank faces are vertical, and a pick is required to dislodge the gravel, and it is possible to break out large chunks in which the smaller pebbles are firmly cemented together, the gravel will make a satisfactory road material.

The term *road metal*, meaning road material, is often used in technical literature, and includes such materials as gravel, broken stone, and slag.

3. Broken Stone.—A good quality of stone should be selected for road metal. The stone should be hard, tough, and durable, and should, if used in the construction of water-bound broken-stone roads, have good binding properties. It should offer a high degree of resistance to abrasion, but need not necessarily be of high crushing strength. It should also be of such quality as not to soften or deteriorate under the action of the atmosphere. Toughness and resistance to abrasion are two very essential qualities.

The varieties of rock most used for road metal are as follows: Trap, syenite, granite, chert, limestone, sandstone, and quartz. These are named in the order of their relative values. Field stones frequently make a satisfactory material for light-traffic roads. Such stones are extremely variable in composition, and hence wearing courses composed of them may wear unevenly.

TESTING OF BROKEN STONE

4. Various Testing Methods.—To form an opinion as to the probable endurance of a stone for road purposes, the best test is actual use in the roadway; but, as this is not always possible, on account of the time involved, more rapid methods must be employed. The laboratory tests generally used include the determination of the specific gravity, the absorptive capacity, the resistance to abrasion, toughness and hardness, and the cementing capacity. Chemical and microscopic analyses are sometimes made, and often furnish information of importance. The relative values of the results of tests, as listed in the following descriptions, are those proposed by the U. S. Bureau of Public Roads, after extensive investigation.

5. Specific Gravity Test.—Committee D-4, on Road and Paving Materials, of the American Society for Testing Materials, recommends that the apparent specific gravity shall be determined in the following manner:

The sample, weighing 1,000 grams and composed of pieces approximately cubical or spherical in shape and retained on a screen having 1.27-centimeter ($\frac{1}{2}$-inch) circular openings, shall be dried to constant weight at a temperature between 100° and 110° C. (212° and 230° F.), cooled, and weighed to the nearest .5 gram. Record this weight as weight A. Immerse the sample in water for 24 hours, surface-dry individual pieces with the aid of a towel or blotting paper, and weigh, recording this weight as weight B. Place the sample in a wire basket of approximately $\frac{1}{4}$-inch mesh and about 12.7 centimeters (5 inches) square and 10.3 centimeters (4 inches) deep, suspend in water from center of scale pan, and weigh. Record the difference between this weight and the weight of the empty basket suspended in water as weight C, the weight of the saturated sample immersed in water.

The apparent specific gravity shall be calculated by dividing the weight of the dry sample A by the difference between

the weights of the saturated sample in air B and in water C, as follows:

$$\text{Apparent specific gravity} = \frac{A}{B - C}$$

Since the apparent specific gravity includes the voids in the specimen, it is therefore always less than or equal to but never greater than, the true specific gravity of the material.

6. Absorption Test.—The committee referred to in Art. 5 recommends that the absorption of water per cubic foot of rock shall be determined by the following method: (1) A sample weighing between 29 and 31 grams and approximately cubical in shape shall be dried in a closed oven for 1 hour at a temperature of 110° C. (230° F.) and then cooled in a desiccator for 1 hour; (2) the sample shall be rapidly weighed in air; (3) trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; (4) after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as possible in distilled water having a temperature of 25° C. (77° F.); (5) allow the sample to remain 48 hours in distilled water maintained as nearly as practicable at 25° C. (77° F.), at the termination of which time bring the water to exactly this temperature and weigh the sample while immersed in it; (6) the number of pounds of water absorbed per cubic foot of the sample shall be calculated by the following formula:

$$\text{Pounds of water absorbed per cubic foot} = \frac{W_2 - W_1}{W - W_1} \times 62.24$$

in which W = weight, in grams, of sample in air;

W_1 = weight, in grams, of sample in water just after immersion;

W_2 = weight, in grams, of sample in water after 48 hours' immersion;

and 62.24 = weight, in pounds, of a cubic foot of distilled water having a temperature of 25° C. (77° F.).

The final value accepted shall be the average of three determinations made on three different samples according to the method just described. The specific gravity and absorptive capacity of the usual road building stones are given in Table I.

TABLE I

SPECIFIC GRAVITY AND ABSORPTIVE CAPACITY OF STONES COMMONLY USED FOR ROAD BUILDING

Kind of Stone	Specific Gravity		Water Absorbed Pounds per Cubic Foot	
	Minimum	Maximum	Minimum	Maximum
Trap	2.80	3.00	.12	3.00
Syenite	2.15	3.05	.05	3.06
Granite	2.00	3.00	.04	3.00
Chert	2.00	3.00	.25	8.27
Limestone	2.00	2.85	.02	13.22
Sandstone	1.90	3.25	.07	14.00
Quartz	2.15	3.15	.04	2.95

7. Abrasion Test.—The abrasion test is made by means of the Deval machine, Fig. 1. It consists of a series of cast-iron cylinders *a* attached by means of the clamping rods *b* to a revolving frame *c*, supported by the bearings *d* and driven by the pulley *e*. Each cylinder is closed at one end and furnished with a tightly fitting cover at the other end. The longitudinal axes of the cylinders make an angle of 30 degrees with the horizontal, as by mounting the cylinders in this manner the rock is thrown from one end of the cylinders to the other while the frame revolves. The rock to be tested is broken in nearly uniform pieces, about 50 pieces weighing approximately 5 kilograms constituting a test sample. The cylinders are required to make 10,000 revolutions to complete a test. The quantity of the worn-off material that will pass through a $\frac{1}{16}$-inch mesh sieve is considered as the amount of wear. This may be expressed either as the per cent. of

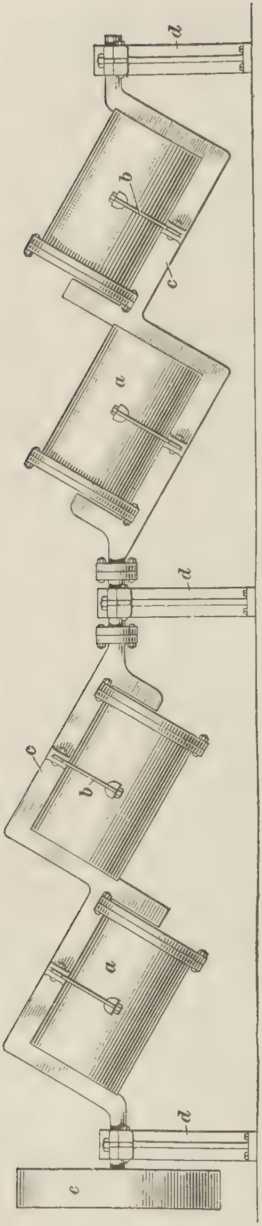


Fig. 1

the kilograms of material used in the test, or the *French coefficient* may be given; that is,

$$\text{Coefficient of wear} = \frac{400}{W}$$

where W = weight, in grams, of the detritus under .16 centimeter ($\frac{1}{16}$ inch) in size per kilogram of rock tested.

A French coefficient of wear under 8 is considered low; from 8 to 12 is considered average, and over 12 high.

8. Toughness Test.—The test for toughness is made in an impact machine, of which there are several varieties. In the machine shown in Fig. 2, known as the *Page impact machine*, a hammer *a*, guided by the rods *b*, is lifted periodically by the traveling chain *c*, the height to which the hammer is lifted being governed by the stop *d*, which is adjusted by the mechanism at *e*. There is an intervening plunger *f* between the hammer and the test piece *g*.

The usual test piece consists of a cylinder 25 millimeters in diameter and 25 millimeters in height, cut perpendicular to the cleavage of the rock. The test consists of a 1-centimeter fall of a hammer weighing 2 kilograms for the first blow, and an increased fall of 1 centimeter for each succeeding blow until failure of the test piece occurs.

The number of blows necessary to destroy the test piece is used to represent the toughness. A result under 8 is low, 8 to 12 average, over 12 is high. The relative toughness of the various rocks available for construction can thus be determined.

9. Hardness Test.—The test for hardness is made by means of a Dorry machine, Fig. 3, which consists of a revolving steel disk *a* on which is fed a standard quartz sand through the funnels *b*. The grains of sand must pass through a 30-mesh and be retained by a 40-mesh sieve. Rock cores, 25 millimeters in diameter, are cut from the rock that is to be tested and their faces are ground off level by suitable machines. Two such cores, placed in dies, are weighed and then inserted in the guide cylinders *c* so that one face of each core rests on the disk *a*, by which it is ground. When the disk has made 1,000 revolutions, the test piece is reversed and the other face is ground for the same number of revolutions. The loss in weight of the specimen is determined at the end of each 1,000 revolutions, and the average loss in weight is used in stating the hardness of the rock.

The hardness is expressed by the formula,

$$\text{Hardness} = 20 - \frac{W}{3}$$

where W = loss in weight, in grams, per 1,000 revolutions.

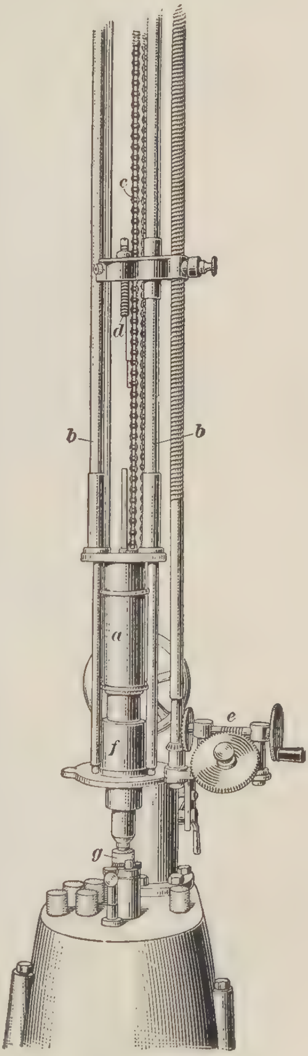


FIG. 2

A coefficient of hardness under 15 is called low, from 15 to 18 average, and over 18 hard.

10. Cementation Test.—The test for ascertaining the cementing value of rock is made as follows: 500 grams of the rock to be tested is broken to pass a $\frac{1}{2}$-inch mesh sieve, 90 cubic centimeters (3.02 ounces) of water is added, and the charge is ground in a ball mill by two steel shot, weighing

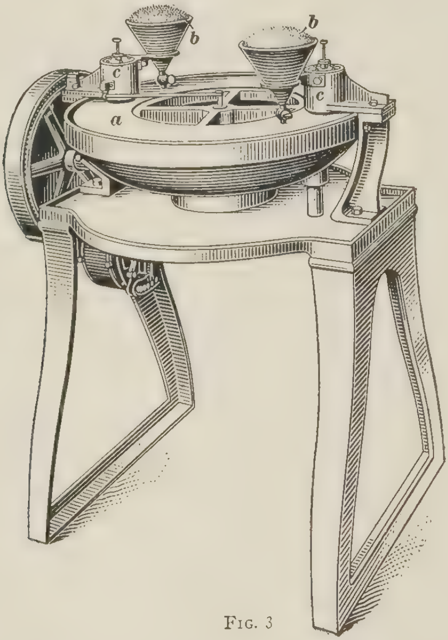


FIG. 3

together 20 pounds, for $2\frac{1}{2}$ hours at a rate of 2,000 revolutions per minute. The dough thus formed is removed and made into five test pieces by means of a metal die, 25 millimeters in diameter, the dough in the die being subjected for an instant to a pressure of 132 kilograms per square centimeter in a hydraulic press. The cylindrical briquette thus formed, 25 millimeters in height, is placed in an impact machine, Fig. 4, used for testing the briquette. In this machine a 1-kilogram hammer *a* is raised by a revolving

cam b to a height of 1 centimeter. The hammer falls on a plunger c and transmits the energy of its blow through the plunger to the test piece d. The instrument is provided with a self-recording apparatus consisting of the paper-covered cylinder e and a lever f provided with a pencil pointer which registers each blow struck until the test piece fails. The average of the number of blows on five briquettes is taken

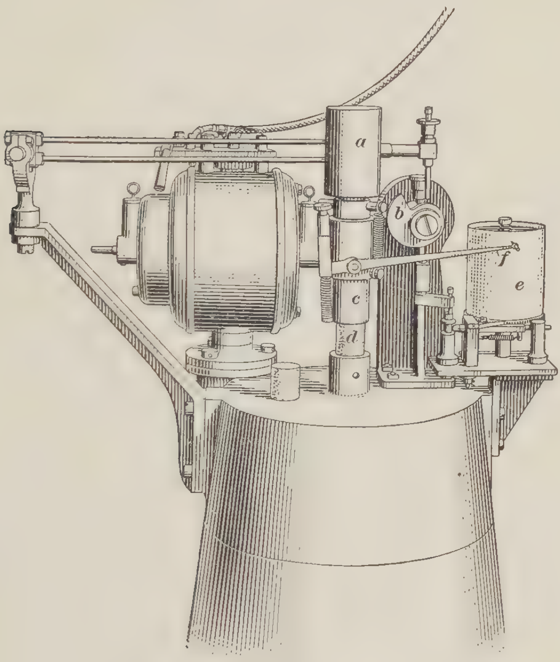


FIG. 4

as a result of the test. A result under 25 is low, 25 to 75 average, and over 75 high.

11. Mechanical Analysis.—The proportions of the various sizes contained in any one sample can be ascertained by passing the sample through screens and sieves of different sizes, the proportions retained on any screen or sieve or passing through it being determined by weight. The screens used in making mechanical analyses of gravel or stone have round

holes, the diameters varying from $3\frac{1}{2}$ inches to $\frac{1}{4}$ of an inch in size. The sieves used in making mechanical analyses of sand and other fine materials are made of wire and have square openings. The sizes vary from a sieve having 10 openings to the linear inch down to one having 200 openings. The sieves are designated as 10 mesh, 40 mesh, 200 mesh, etc., depending on the number of openings per linear inch.

STONE BLOCKS

12. Properties.—Stone blocks for paving are generally of granite, but are sometimes cut from sandstone, quartzite, and trap rock. The stone blocks should be of such quality that they will resist shocks, crushing, and weathering, and will not wear round and smooth under the action of traffic. They should be of uniform quality and texture, without seams, scales, or discolorations. The planes of cleavage of granite are such that it is easy to make blocks from it. The trap rocks are harder and tougher than the granites and are not so easily made into blocks. Sandstone blocks are not usually suitable for streets that carry heavy traffic. They wear more uniformly than granite blocks, but they often wear very rapidly. The Medina and Potsdam sandstones, which are found in New York State, have been used in pavements to a considerable extent throughout the state. In Rochester, N. Y., dressed Medina stone has been used with excellent results on the main streets taking heavy traffic. A large amount of quartzite has been laid in Chicago with good results.

13. Tests.—The qualities of the stone of which a block is composed can be determined by submitting samples of the stone to the specific gravity, absorption, abrasion, toughness, and hardness tests, in the manner already described.

PAVING BRICK

14. Manufacture.—Clay to be used for the manufacture of brick should be fusible, plastic, and capable of being heated to a high temperature without losing its shape. Sur-

face clays, therefore, are very little used, although they are extensively employed in the manufacture of building brick. Many brands of paving brick are now made from shale. Shales are chemically of the same composition as clays, but have become hardened and have a laminated structure. They are found in large deposits in stratified beds.

15. Characteristics.—Paving brick should be thoroughly annealed, tough, durable, regular in size and shape, and evenly burned. When broken, the brick should show a dense, stone-like body, free from lime, air pockets, cracks, or marked laminations. Kiln marks should not exceed $\frac{3}{16}$ of an inch in depth, and at least one edge of the brick should show but slight marks. All bricks so distorted in burning as to lie unevenly in the pavement should be rejected.

16. Testing Brick.—The most common test employed for brick is the *rattler test*, which gives some indication as to the wearing qualities of the brick when subjected to the action of traffic. Other tests sometimes made are the absorption, cross-breaking, and the crushing tests.

Rattler Test.—The standard rattler, Fig. 5, is a machine that consists essentially of an iron barrel a about 28 inches in diameter and of about the same length. The side of the barrel consists of 14 steel staves b, and two heads c, with trunnions, serve as the ends. The heads and staves are lined with metal plates which can be removed and replaced when worn. The barrel is supported on a cast-iron frame and is driven by the pulley d and the gears e and f so as to revolve with its charge at a rate of $29\frac{1}{2}$ to $30\frac{1}{2}$ revolutions per minute.

The abrasive charge consists of two sizes of spherical shot, the larger size being about 3.75 inches in diameter when new, and weighing about $7\frac{1}{2}$ pounds each, the smaller size being 1.875 inches in diameter, and weighing .95 pound each. Ten of the large shot are used and enough of the small shot to bring the total weight of the shot up to 300 pounds. The bricks are first dried for a period of at least 3 hours at a tem-

perature of 100° F. Ten bricks are weighed and then placed in the rattler with the charge of shot. After the rattler has made 1,800 revolutions the bricks are taken out and their loss in weight is determined. All pieces of brick that are under 1 pound in weight should be excluded.

Many specifications require that, in the rattler test, the bricks shall lose not more than 22 per cent. of their weight.

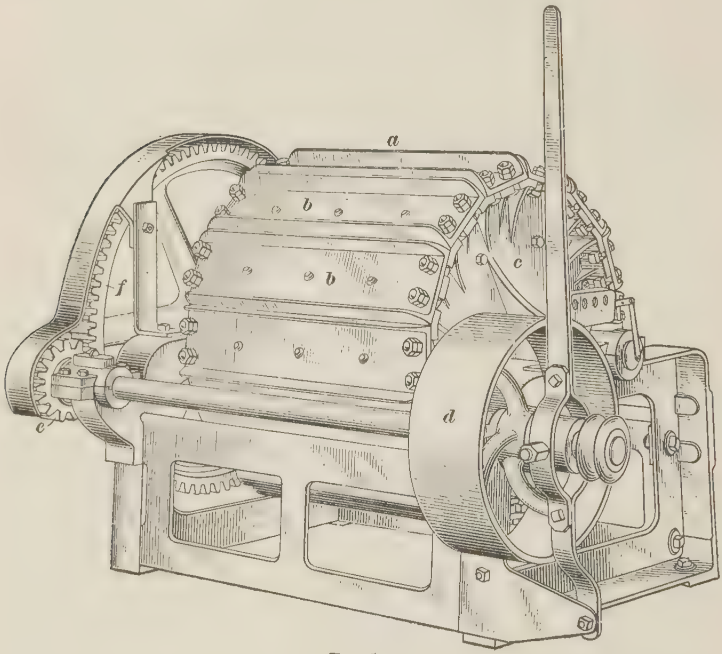


Fig. 5

In order to insure that brick of uniform quality is supplied for a given pavement, in addition to the above requirement, there should be an additional stipulation that the maximum loss in any one brick in the rattler test should not exceed 27 per cent. Another method of covering this requirement is to state that the maximum and minimum losses of an individual brick should not vary more than 10 per cent.

Absorption Test.—The absorption test is made on five bricks which have been through the rattler test and whose

weights are known. They are immersed in water for 48 hours and then weighed again. From these weights, before and after immersion, the percentage of water absorbed can be computed. Specifications generally do not allow over $3\frac{1}{2}$ per cent. absorption.

Cross-Breaking Test.—The cross-breaking test is made by placing a brick on edge on supports that are 6 inches apart. The breaking load is applied at the center of the brick. The average of the results on ten bricks is used in computing the modulus of rupture, R, by means of the following formula:

$$R = \frac{3\,W\,L}{2\,b\,d^2}$$

in which R = modulus of rupture, in pounds per square inch;
b = breadth of brick, in inches;
d = depth of brick, in inches;
L = length of brick between supports, in inches;
W = average breaking load, in pounds.

Cross-breaking resistance ranges from 1,000 to 3,500 pounds per square inch of cross-section.

WOOD BLOCKS

17. Selection of Material.—Experience has shown that there are only a few woods in this country which are commercially suitable for the manufacture of good blocks. Specifications differ slightly, but the best practice admits the use of southern yellow pine, Norway pine, tamarack, and black gum. In order to secure pavements of uniform quality, it is necessary to use only good-grade timber free from loose knots, worm and knot holes, and shakes.

18. Decay and Preservation.—The decay of wood is due to a low form of plant life called *fungi*. The fungi attack the wood from the outside, and if the wood is in the right condition for the spores to grow, they will ultimately penetrate the entire structure of the wood. Heat, air, and moisture are necessary for the growth of fungi. Since air and heat are always present, it is necessary, in most climates, to

eliminate the moisture as the first step in destroying the fungus life. In fact, this is partly accomplished when timber is seasoned. The timber is piled so as to permit free circulation of air around each piece, and in this manner the moisture content can be reduced 15 to 18 per cent.

A more effective method of timber preservation is to treat the timber with some preservative that will change the organic matter in the inner structure so that it will not serve as food for the fungi. The use of a preservative treatment will not only preserve the wood from decay, but will also fill the pores and prevent the absorption of other fluids. This is a very desirable property for wood blocks to possess, since it tends to minimize expansion, to increase the resistance to wear, and to make the pavement more sanitary. The preservatives used are copper sulphate, zinc chloride, creosote, and bichloride of mercury. The processes in the United States are restricted to those using creosote and zinc chloride. Of these two the creosoting process is by far the most common, and is the better, particularly if the wood is to be used where it will be wet, since the zinc chloride is soluble in water and will leach out of the wood.

19. Absorption Test.—The success of wood-block pavements depends largely upon rigid requirements covering the amount of water that the blocks will absorb under stated conditions. Blow-outs of wood-block pavements occurring after heavy rains are undoubtedly caused, in most cases, by the absorption of large amounts of water by improperly treated blocks. The treated blocks should show such waterproof qualities that, after being dried in an oven at a temperature of 38° C. (100° F.) for a period of 24 hours, weighed and then immersed in clear water for a period of 24 hours and again weighed, the gain in weight will not be more than $3\frac{1}{2}$ per cent. when tested at the place where manufactured, and not more than 5 per cent. when samples are taken from the blocks delivered on the work.

BITUMINOUS MATERIALS

ASPHALT, PETROLEUM, AND TAR

20. Application in General.—In the treatment and construction of highways, bituminous materials are used in a variety of ways, such as for short-lived dust layers, or dust *palliatives*, and as materials for construction and maintenance of bituminous surfaces, bituminous pavements, and block pavements in connection with which bituminous fillers or impregnating materials are employed.

21. Bituminous Materials Used for Roads and Pavements.—*Bitumen* is an ingredient of all bituminous materials, and consists of those hydrocarbons and their non-

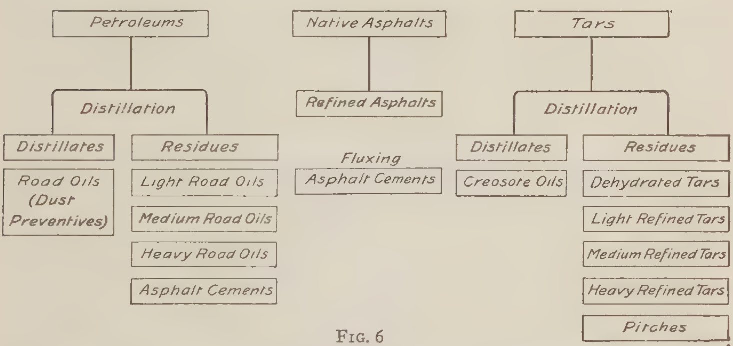


FIG. 6

metallic derivatives which are soluble in chemically pure carbon disulphide. These hydrocarbons and derivatives may be gases, liquids, viscous liquids, or solids. The crude materials from which are manufactured the bituminous materials that are used in the construction and maintenance of roads and pavements may be classified as rock asphalts, asphalts, petroleums, and tars. The diagrams, Fig. 6, which are based on diagrams compiled and arranged by Prévost Hubbard, show graphically the interrelationship between the principal types of bituminous materials and their derivatives.

The three bituminous materials, asphalts, petroleums, and tars, form the basis of the diagrams. The three diagrams show the order in which the principal bituminous materials used in highway work are obtained by processes of refining, after water and other impurities have been removed from the materials. For example, during the distillation of tar, a distillate is obtained known as creosote oil which is used as a preservative in the manufacture of wood paving blocks. By distillation of tar, various residues may be obtained. Those used in highway work may be designated as dehydrated tars, meaning tars from which water has been removed, light refined tars, heavy refined tars, and pitches.

SOURCES AND MANUFACTURE OF BITUMINOUS MATERIALS

22. The principal sources of the rock asphalts, asphalts, petroleums, and tars, from which are manufactured the various bituminous materials used in the treatment and construction of highways, are given in the following articles:

23. Rock Asphalts.—The rock asphalts in common use in Europe are composed of limestones and sandstones impregnated with 7 to 14 per cent. of asphalt. The principal sources are in France, Switzerland, Alsace, Sicily, and Germany. The rock asphalts of the United States are found principally in California, Kentucky, Oklahoma, and Utah.

24. Asphalts.—Asphalts may be considered as belonging to one of the three following classes: (1) Solid or semisolid native bitumens; (2) solid or semisolid bitumens obtained by refining petroleums; (3) solid or semisolid bitumens which are combinations of the two classes of bitumens mentioned with petroleums or their derivatives. The Alcatraz, Bermudez, Cuban, Gilsonite, Maracaibo, and Trinidad asphalt cements contain asphalt as defined under the first class; that is, asphalts that are solid or semisolid native bitumens. The asphalts obtained by refining such asphaltic oils as are obtained from the fields of California, Mexico, Southern Illinois, and Texas, come within the second group; that is,

they are solid or semisolid bitumens obtained by refining petroleums. The asphalts made from a combination of refined petroleum and Gilsonite, a solid native bitumen, are covered by the third class; namely, asphalts that are solid or semisolid bitumens which are combinations of the two classes of bitumens mentioned with petroleums or their derivatives.

25. Petroleums.—Petroleum occurs in nature as liquid bitumen. Asphaltic oils and asphalt cements are manufactured from semiasphaltic and asphaltic petroleums obtained principally from the California, Illinois, Kansas, Oklahoma, Texas, Mexico, and Trinidad fields.

Asphaltic cement is a refined asphalt which has been mixed with some solvent to increase its plasticity, adhesiveness, and tenacity. The asphaltic cements produced from petroleum by straight distillation vary in characteristics according to the type of petroleum distilled.

Cut-back asphaltic cements are those which have been fluxed with a distillate. A light volatile distillate is generally used, as the common reason for employing a distillate flux is temporarily to soften or liquefy an asphalt cement.

26. Tars.—The refined tars and pitches used in the construction and maintenance of various types of roads and pavements are manufactured from gas-house coal tars, coke-oven tars, and water-gas tars.

Gas-house coal tars are produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal. Coke-oven tars are produced in by-product coke ovens in the manufacture of coke from bituminous coal, and water-gas tars are produced by destructively distilling oil vapors at high temperatures in the manufacture of carburetted water gas.

PRINCIPAL TESTS OF BITUMINOUS MATERIALS

27. Nature and Purpose of Tests.—Various tests have been devised in order to determine the physical and chemical properties of bituminous materials. Tests are made for control of the manufacture of bituminous materials, to

obtain a record of the properties of materials used, and are stipulated in specifications to secure the materials desired for use in the construction and maintenance of roads and pavements. The tests generally made include those for flash point, melting point, consistency, ductility, specific gravity, solubility in carbon disulphide, solubility in carbon tetrachloride, solubility in paraffin naphtha, distillation, and fixed carbon.

The first five tests enumerated are described in detail in the following articles. Solubility, distillation and fixed carbon tests involve complex chemical analysis and will not be given here.

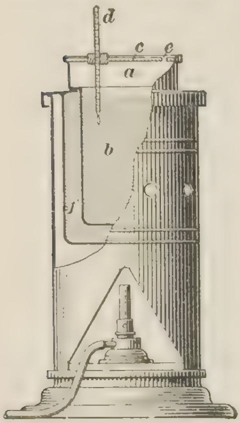


FIG. 7

28. Flash Point.—The material *b* to be tested for flash point is placed in a copper oil cup *a*, Fig. 7, which is heated in a water or cottonseed-oil bath *f* by a small Bunsen burner. The cup has a glass cover *c*, fitted with a thermometer *d*. A testing flame is inserted from time to time in the hole *e*, and the appearance, for a few seconds, of a faint bluish flame over the entire surface of the bituminous material will show that the flash point has been reached; the temperature at this point is then recorded as the flash point.

29. Melting Point.—The material to be tested for melting point is melted and molded into the shape of a ½-inch cube. The cube is placed on a wire and suspended with its base 1 inch above the bottom of a beaker, which is placed in a water or cottonseed-oil bath over a Bunsen burner. The temperature of the cube is then raised until the material softens and touches the bottom of the beaker. The temperature at this point of the operation is considered the melting point of the material.

30. Consistency.—The consistency of bituminous materials is determined by the Engler viscosimeter, by the New

York Testing Laboratory float apparatus, or by the penetrometer.

With the *Engler viscosimeter*, Fig. 8, the viscosity of liquid bituminous materials is determined by noting the time required for a given amount of material, of a given temperature, to flow through a very small orifice. The viscosimeter consists of a brass vessel *a*, for holding the material to be tested. To the bottom is fitted an outflow tube *c* with diameter at top and bottom of 2.9 and 2.8 millimeters, respectively. The tube may be closed by the hardwood stopper *d*. Passing through the cover *b*, a thermometer *e* gives the temperature of the material, which is heated by the water or cottonseed-oil bath contained in the brass jacket *f*. The tripod *g* supports this apparatus and the ring burner *h* which heats the bath. The molten material passing out through the orifice is collected in the measuring cylinder *i*. The result of the test should be expressed as *specific viscosity*, which equals the number of seconds required for the passage of a given volume of the bituminous material, at the temperature used, divided by the number of seconds required for the passage of the same volume of water at 25° C. (77° F.)

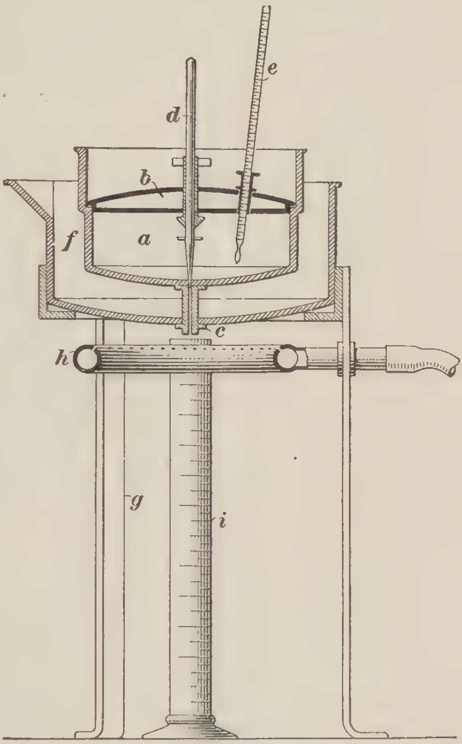


Fig. 8

FIG. 9

31. *The New York Testing Laboratory float apparatus*, Fig. 9, consists mainly of an aluminum float *a* and a brass collar *b* which may be screwed into the bottom of the float. One float may be used with a number of brass collars. A small quantity of the material to be tested is heated in a metal spoon until quite fluid. The brass collar *b* is then filled with this fluid and immediately cooled off in ice water, thus forming a plug of bituminous material in the brass collar. The collar and contents are then screwed into the bottom of the aluminum float and the apparatus is placed on the surface of a water bath *c*. As the plug of bituminous material in the collar becomes warm and fluid, due to the heat from the water bath which is maintained at any temperature desired for the test, the material is gradually forced upwards and out of the collar until water gains entrance to the saucer and causes it to sink. The time in seconds between placing the apparatus on the water and when the float sinks is taken as the measure of consistency.

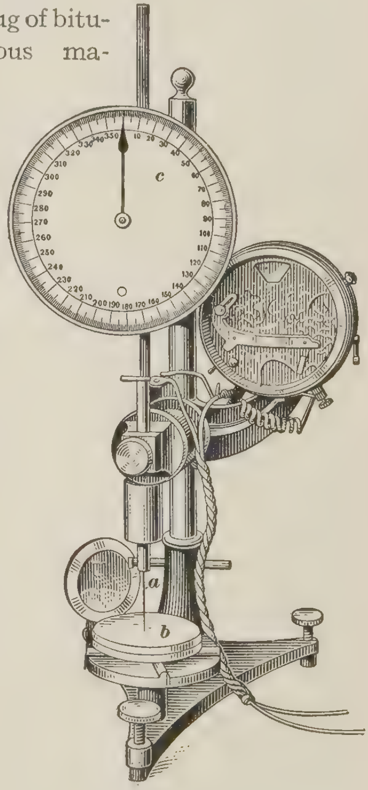


FIG. 10

32. The penetration test for determining the consis-

tency is made with a *penetrometer* similar to that shown in Fig. 10. A weighted standard needle *a* is allowed to penetrate into the material contained in the saucer *b* and maintained at a given temperature. The movement of the needle in a given period is indicated on the dial *c*, on which each division represents .01 millimeter.

The temperatures, weights, and periods of time that are commonly employed in penetrometer tests are as follows: Penetration at 4° C. with a weight of 200 grams for 1 minute; penetration at 25° C. with a weight of 100 grams for 5 seconds;

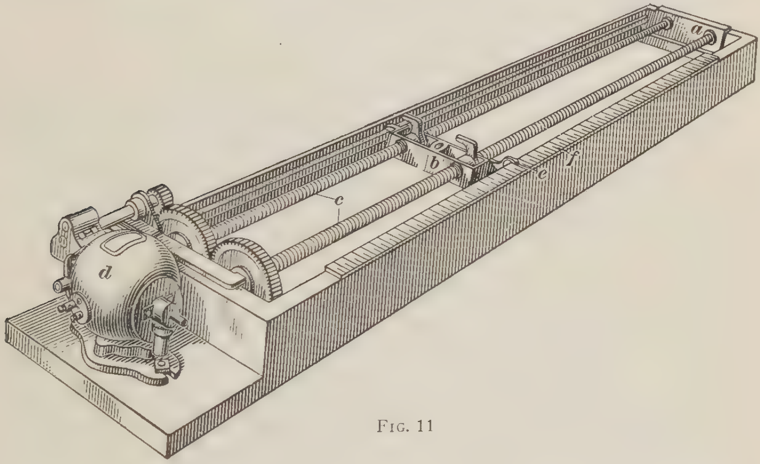


FIG. 11

penetration at 46° C. with a weight of 50 grams for 5 seconds. When the penetration of a material is mentioned without reference to temperature, weight of the load, or time, it is to be understood that reference is made to the penetration at the normal temperature of 25° C. (77° F.) with a weight of 100 grams for 5 seconds. The unit of penetration is .1 millimeter. In literature and specifications, the penetration is referred to in terms of the above unit; thus, a penetration of 6.4 millimeters is referred to as 64.

33. Ductility.—In the ductility test, a briquet of the material to be tested is formed in a standard briquet mold. The briquet, with clips attached at the ends, is placed in a

ductility testing machine similar to that shown in Fig. 11, which is filled with water at a temperature of 4° C. or 25° C. The two clips are attached to the blocks *a* and *b* and the block *b* is pulled away from *a* by the revolving screws *c* driven by the motor *d* by means of suitable gearing. The block *b* is provided with a pointer *e* moving along the centimeter scale *f*, which can be adjusted into such a position that the pointer stands at zero before the experiment is started. The briquet is pulled apart at a uniform rate, and the distance in centimeters registered at the time of rupture of the thread of bituminous material is taken as the measure of ductility.

34. Specific Gravity.—The *pycnometer* method for determining the specific gravity of both fluid and semisolid bitumens, as described by Hubbard and Reeve in Bulletin No. 38, United States Department of Agriculture, is as follows: The **pycnometer** consists of a fairly heavy, straight-walled glass tube, 70 millimeters long and 22 millimeters in diameter, ground to receive a solid glass stopper with a hole of 1.6 millimeters bore in place of the usual capillary opening. The lower part of the stopper is made concave in order to allow all air bubbles to escape through the bore. The depth of the cup-shaped depression is 4.8 millimeters at the center. The stoppered tube has a capacity of about 24 cubic centimeters and when empty weighs about 28 grams.

For semisolid bitumens which are too soft to be broken and handled in fragments, the following method of determining specific gravity has been successfully employed. The clean, dry pycnometer is first weighed empty, and this weight is called *a*. It is then filled in the usual manner with freshly distilled water at 25° C., and the weight is again taken and called *b*. A small amount of the bitumen should be placed in a spoon and brought to a fluid condition by the gentle application of heat, with care that no loss by evaporation occurs. When the material is sufficiently fluid, enough is poured into the dry pycnometer, which may also be warmed, to fill it about half full, without allowing the material to touch the sides of

the tube above the desired level. The tube and contents are then allowed to cool to room temperature, after which the tube is carefully weighed with the stopper. This weight is called c. Distilled water, at 25° C., is then poured in until the pycnometer is full. After this the stopper is inserted, and the whole cooled to 25° C. by a 30-minute immersion in a beaker of distilled water maintained at this temperature. All surplus moisture is then removed with a soft cloth, and the pycnometer and contents are weighed. This weight is called d. From the weights thus obtained, the specific gravity of the bitumen may be readily calculated by the following formula:

$$\text{Specific gravity} = \frac{c-a}{(b-a)-(d-c)}$$

The specific gravity of fluid bitumens may be determined in the ordinary manner with this pycnometer by completely filling it with the material and dividing the weight of the bitumen thus obtained by that of the same volume of water.

35. Use of Different Tests.—The tests required by a given specification depend upon the kind of bituminous material employed and the purpose for which it is used. For example, a specification for a refined tar to be used as a bituminous cement in a bituminous-concrete pavement in which the aggregate consists of broken stone, would include tests for specific gravity, solubility in carbon disulphide, consistency as determined by the New York Testing Laboratory float apparatus, melting point, distillation, specific gravity of total distillate, and melting point of pitch residue remaining after distillation. In the case of an asphalt cement to be used in the type of construction mentioned, the tests referred to in the specifications would include specific gravity, flash point, penetration at 4° C. and at 25° C., melting point or consistency as determined by the New York Testing Laboratory float apparatus, loss on evaporation at 163° C. and penetration of the residue from evaporation, solubility in carbon disulphide, solubility of bitumen in carbon tetrachloride, solubility of bitumen in paraffin naphtha, and fixed carbon.

SPECIFICATIONS FOR BITUMINOUS MATERIALS

36. Maximum and Minimum Limits of Consistency.—One of the most important tests of the physical properties of bituminous materials is that for consistency. Maximum and minimum limits covering consistency are essential parts of all specifications for bituminous materials. Such limitations are of particular value since it is possible by means of them to secure the grade of a given type of bituminous material that is most suitable for any method of use, and, furthermore, because it is practicable thus to insure reasonable uniformity in the consistency of the bituminous material supplied for a given piece of work. It is apparent that the range in limits should be as narrow as the practicable manufacture of the bituminous materials will permit.

37. The utilization of the various standard methods employed for the determination of consistency, that is, with the Engler viscosimeter, the New York Testing Laboratory float apparatus, and the penetrometer, depends upon the characteristics of the materials. For example, the Engler viscosimeter is generally employed to determine the consistency of liquid bituminous materials; the New York Testing Laboratory float test for the determination of the consistency of semisolid and solid tars and pitches; and in most cases the penetrometer is used for the determination of the consistency of semisolid and solid asphaltic materials. In order to show the methods of stating consistency and the variations in consistency of a given type of material dependent upon its use, the following examples are given:

Coal-Gas Tar for Cold Application to Broken-Stone and Gravel Roads.—When tested by means of the Engler viscosimeter at 40° C. (104° F.), the specific viscosity of the first 50 cubic centimeters of material passing the orifice of the viscosimeter shall be not less than 8 nor more than 13.

Coal-Gas Tar for the Construction of Bituminous Surfaces on Broken-Stone and Gravel Roads.—When tested by means of the New York Testing Laboratory float apparatus, the

float shall not sink in water maintained at 50° C. (122° F.) in less than 40 seconds nor more than 100 seconds.

Coal-Gas Tar Cement for Use in the Construction of Bituminous Macadam Pavements.—When tested by means of the New York Testing Laboratory float apparatus, the float shall not sink in water maintained at 50° C. (122° F.) in less than 150 seconds nor more than 180 seconds.

Asphalt cement, when tested with a standard No. 2 needle by means of a Dow penetrometer (or other penetrometer giving the same results as the Dow machine), shall show penetrations within the following limits for the conditions stated, the penetrations being expressed in hundredths of a centimeter:

For use in the construction of bituminous macadam pavements: 100-gram load, 5 seconds, at 25° C. (77° F.), from 100 to 120; 200-gram load, 1 minute, at 4° C. (39° F.), not less than 50.

For use in the construction of bituminous concrete pavements having an aggregate composed of one product of a stone-crushing plant varying in size from $\frac{1}{8}$ inch to $1\frac{1}{4}$ inches: 100-gram load, 5 seconds, at 25° C. (77° F.), from 75 to 90; 200-gram load, 1 minute, at 4° C. (39° F.), not less than 35; 50-gram load, 5 seconds, at 46° C. (115° F.), not more than 250.

For use in the construction of sheet asphalt pavements: 100-gram load, 5 seconds, at 25° C. (77° F.), from 65 to 75; 200-gram load, 1 minute, at 4° C. (39° F.), not less than 35; 50-gram load, 5 seconds, at 46° C. (115° F.), not more than 250.

For use as filler in brick and stone-block pavements: 100-gram load, 5 seconds, at 25° C. (77° F.), from 30 to 40; 200-gram load, 1 minute, at 4° C. (39° F.), not less than 18; 50-gram load, 5 seconds, at 46° C. (115° F.), not more than 70.

38. Alternative and Blanket Specifications.—The type of specification known as *alternative specification* describes the physical and chemical properties of a number of different kinds of material that would be accepted for a given purpose. Thus, for example, in the case of asphalt cement for a bitumi-

nous-concrete pavement, materials corresponding to at least five different specifications for specific gravity and penetration might be suitable for the work, though the limits of the physical and chemical requirements of each might be as narrow as the several processes of manufacture would allow. The following specifications, *A* to *E*, inclusive, illustrate the limits that, under alternative specifications, might be allowed for specific gravity and penetration for bitumen at 25° C. (77° F.)

	A	*B*	*C*	*D*	*E*
Specific gravity..	.97–1.00	1.00–1.03	1.03–1.04	1.025–1.05	1.04–1.06
Penetration	75–90	90–100	70–90	85–95	140–160

Since bitumen complying with any one of the sets of requirements will be suitable for the job, a contractor under such specifications can bid on the one he is best able to furnish, which may result in economy.

39. A *blanket specification* would cover in one set of requirements pertaining to physical and chemical properties, all the types of material that could be used for the construction of the pavement in question. If an attempt were made to cover by blanket specifications the same grades of material indicated by specifications *A* to *E*, the limits of specific gravity would be .97 to 1.06, and the limits for penetration would be 70 to 160.

For use in the type of pavement in question, each specific type of bituminous cement is at its best when it conforms to a certain definite penetration test. In the case of the bituminous concrete pavement of the type mentioned in Art. **38**, the proper penetration limits for a California asphalt lie between 70 and 90, while for a fluxed Bermudez asphalt to be used in exactly the same type of pavement and under the same conditions, the penetration limits should be between 140 and 160. It is evident that to attempt to cover the penetration limits for both materials in one specification is impracticable. In the first place, such limits as 70 to 160 are so wide apart as to insure but little uniformity in different lots of the same material, and in the second place, an entirely

unsuitable material of one class could be supplied under the maximum or minimum test limits of the other class. It is, therefore, evident that the definite alternative specifications are to be preferred.

ROAD CONSTRUCTION

EARTH AND SAND-CLAY ROADS

SOIL VARIETIES AND METHODS OF DRAINAGE

40. Introductory.—The construction of earth and sand-clay roads consists of grading operations that provide proper drainage through the medium of culverts and drains, and the formation of the wearing course. The construction and maintenance of earth roads is of great importance, particularly in those sections of the country where road-building materials, such as stone and gravel, are not available. In some states the solution of the good-roads problem is based mainly upon the efficient utilization of earth roads. The labors of those who have made the improvement of earth roads a serious study have led to the construction of the sand-clay roads which will be described later.

41. Characteristics of Sand and Clay Soils.—The soil conditions in different localities are so variable that what may be an advisable method of construction in one place will not serve in another. Therefore, a careful examination of the soil is essential. Sand is practically the only soil that makes a better road surface in a wet than in a dry condition. A soil that is largely composed of clay acts just the opposite from sand under the same climatic conditions. In dry weather the clay becomes hard and, if kept in proper shape, makes a good surface. In continued wet weather, however, the water soaks into the clay and softens it, with the result that the surface no longer can support the traffic. An earth road in which the surface is composed of a soil that is a mixture of sand and

clay will, therefore, be much more satisfactory, under most conditions, than one composed of either of these soils alone.

42. Drainage.—One of the principal faults with many earth roads is that they are not properly drained. The want of proper drainage allows the surface to become soft after rains and when the frost is coming out of the ground, with the result that the traffic soon cuts through and in some cases the roads become practically impassable. If subdrains are employed in an intelligent manner, if the surface is kept shaped up so as to throw the water to the side ditches, and if the culverts and ditches are properly constructed and maintained, there is no difficulty in making an earth road readily passable at all times of the year to the traffic for which it is suitable.

43. Surface drainage is accomplished by the following means: (*a*) Longitudinal grade, (*b*) crowning the road, and (*c*) side ditches.

If practicable, the longitudinal grade should not be over 4 per cent., and under no conditions over 6 per cent. The surfaces of earth roads having grades over 4 per cent. are expensive to maintain where there are heavy rains, on account of the erosion of the surface by the rapidly flowing water.

Since the surface of an earth or sand-clay road is not so impervious to water as are surfaces constructed with a material such as stone or gravel, it is generally given more crown. An average crown of about 1 inch to the foot is common, the surface being shaped to follow a circular or other curve or else formed by two or more intersecting planes, as discussed in *Highways*, Part 1.

In no case should the ditches be less than 6 feet in width, as narrow ditches soon become clogged and are unable to carry off the surface water readily, with the result that the water seeps into the roadway. The depth of the ditch should be at least 2 feet 6 inches below the center of the surface of the roadway in order to provide ample waterway. Offtake ditches or other outlets for the water flowing in the longitudinal ditches should be provided, as otherwise the volume of water will exceed the capacity of the ditches.

METHODS OF ROAD CONSTRUCTION

44. Earth Roads.—The following methods of constructing earth roads are recommended by the United States Office of Public Roads*:

The most economical methods and machinery to employ in grading a particular road depend on the character and amount of the work to be done. Where, for example, the grade and cross-section of the road follow closely the original ground surface, most of the necessary grading usually may be done with a grading machine. In the case of embankments built up with material from borrow pits along the sides of the road, an elevating grader frequently may be used to advantage. If material must be moved longitudinally along the road from cuts to fills, in order to bring the surface of the road to the required grade, the work usually must be done either with scrapers or dump wagons. Where a considerable volume of material is to be excavated in a relatively short distance, a small steam shovel with dump-wagon equipment sometimes may be employed economically.

No matter how the grading of an earth road may be accomplished, it usually is economical to bring the road surface to its final shape by means of a grading machine. In making excavations, it is not generally considered practicable to form the crown and side ditches with scrapers or hand tools alone, and the cross-section is, therefore, frequently left approximately flat. The grading machine is then used to produce the required cross-section. After the road has been finished with the grading machine, frequent attention should be given to it until the embankments have finished settling and the surface has become thoroughly compacted by the action of traffic. Generally, a period of several months should elapse after a road is graded before it is considered complete, and such settlements and irregularities as develop during this period should be corrected by the use of either a grading machine or a road drag.

*Bulletin No. 463, United States Department of Agriculture.

45. Sand-Clay Roads.—Sand-clay roads may be divided into three classes, depending on whether they are constructed of (1) top soil, (2) sandy subsoil, or (3) clayey subsoil.

Top-Soil Roads.—There are many places throughout the country where a top soil is found that is a mixture of sand and clay and which serves to make an excellent road. Suitable top soils of this character are composed of a mixture of clay and sand or gravel that does not contain stones over $2\frac{1}{2}$ inches in diameter or an excess of fine sand. The material passing a 100-mesh sieve should be plastic when mixed with a small amount of water. Many miles of roads in the South have been surfaced with from 6 to 14 inches of top soil, consisting of a mixture of sand and clay taken from the adjacent fields.

Sandy Subsoil.—If a sand-clay road is to be constructed of a sandy subsoil, the roadbed is shaped up to the desired crown. The clay is spread on the road in a layer 6 to 10 inches thick at the center, tapering off to a thin layer at the sides. If the construction is begun at the end of the road near the source of supply of the clay, the road will be somewhat compacted during construction by the teams on the work. It is necessary that the clay be thoroughly mixed with the sand and that all lumps be broken up. Dry mixing, or covering the clay layer with sand and leaving it for traffic to mix and compact, will not secure so quick nor so good results as can be obtained by plowing, harrowing, and rolling. The clay should be puddled to secure a thorough mixture with the sand, and hence water is essential to obtain the best construction. If no water is at hand, the mixing should be completed soon after or during rainy weather.

Clayey Subsoil.—If a sand-clay road is to be constructed of a clayey subsoil, the roadbed is shaped up and drained as in the previous case. The surface is then plowed and pulverized as much as possible to a depth of 4 inches. This surface is then covered with a layer of sand 6 to 8 inches thick. In this case the mixing of the clay and the sand should be carried out while the materials are in a dry state. After this preliminary mixing has been accomplished, the further mixing is carried on when the road is wet. The road is finally shaped

up and compacted. It must not be expected that as soon as a sand-clay road is completed it will have a perfect surface. It is only by carefully watching the road and adding sand or clay as required that a satisfactory surface will finally be obtained.

46. Maintenance of Earth and Sand-Clay Roads. The principal work in maintaining an earth or a sand-clay road is to keep the surface smooth and well crowned, so that it will shed water as rapidly as possible. If any depression forms in the surface, water settles in it and softens the road, with the result that a very small depression will work into a large and dangerous hole if not repaired at once. In repairing holes in an earth road, they should be filled with the same kind of material that is used in the surface, since if a harder material than the surrounding earth is used, the surface tends to wear unevenly, as the harder material offers more resistance to traffic. An earth road should have plenty of sunlight and air, and hence the undergrowth at the sides should be kept cut. Ditches and culverts should always be kept clean to give an easy outlet to the water. A large part of the maintenance work of keeping the road in shape can be done either by road scrapers and graders or by road drags.

GRAVEL ROADS

PRINCIPAL FEATURES

47. Advantages of Gravel Roads.—Where gravel of suitable quality is procurable, it forms an excellent road surface at a moderate cost. Highways constructed with a wearing course of gravel have proved suitable for light traffic. In some instances where the traffic consists of light horse-drawn vehicles and touring cars, the gravel road has proved to be superior to the broken-stone road, as it has been less affected by motor traffic and is more easily repaired.

48. Transverse Slope and Crown.—The transverse slope of the subgrade may or may not be parallel to the finished

surface, since the gravel surface is frequently constructed thinner at the edges than at the center of the road. The crown of a gravel road is made from $\frac{1}{2}$ inch to 1 inch to the foot, $\frac{3}{4}$ of an inch to the foot being common practice. There are two principal methods of construction, which will be called the *surface method* and the *trench method.*

METHODS OF CONSTRUCTION

49. Surface Method.—In the *surface method* of constructing roads, the gravel is brought to the road, dumped on the roadbed, and smoothed out to the desired shape, the

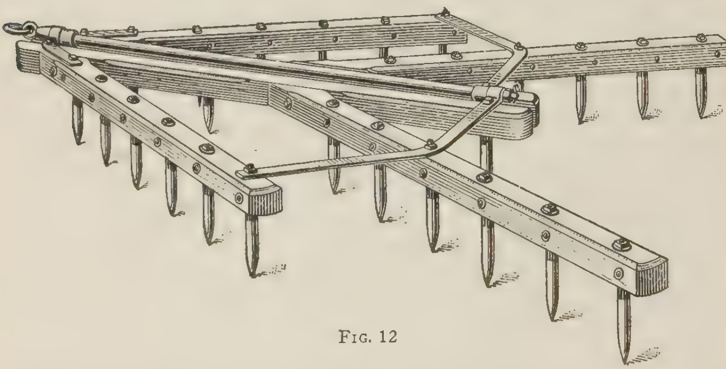


Fig. 12

larger stones being raked over into the bottom of the crust. A spike-tooth harrow, of the form shown in Fig. 12, and a road drag have been successfully used in this part of the work. The width and depth of the gravel crust will depend upon drainage, foundation, and traffic conditions. A depth of from 8 to 15 inches at the center is quite common. As no shoulders are built in the subgrade to hold back the gravel, the edges will spread out during compaction so as to be of very little depth and will form what are known as *feather edges.* More uniform results will be obtained if planks are temporarily laid on edge, at a distance apart a little less than the desired width of surface, and the gravel is filled in between these planks to the required depth. The surface is then rolled, preferably with a grooved roller, until firmly compacted.

A gravel road should be compacted from the bottom up, but never with a smooth-face roller, which has a tendency to compact the uppermost part of the layer before the bottom is consolidated. If the traffic is not too heavy and it can be so regulated as to travel over all parts of the road, the traffic will serve to compact the gravel much better than will a smooth-face roller. In order to take advantage of the rolling afforded by the traffic, the construction may proceed from the end of the road nearer the source of supply of the gravel. Since narrow wheels are liable to rut the surface, the material should be raked into the ruts as they are formed and the whole surface kept in as smooth a condition as possible. When the gravel is deposited in one layer the lower part never gets the compaction that it should. It is good practice, therefore, to build the road in courses, compacting each course as it is laid.

50. Trench Method.—The trench method of road construction includes the construction of shoulders for the purpose of maintaining the edges in position and giving them the required depth. The shoulders should be of firm earth or other suitable material and should be high enough to give a depth of 8 inches of compacted material in the road. From one to three courses are used in the trench method of constructing gravel roads. In some cases the crust is constructed with a uniform thickness, while in others a varying thickness is employed, the maximum being at the center of the roadway. The total thickness of the several courses, which may be from 6 to 10 inches, depends upon the traffic and the nature of the subgrade. A heavy traffic and a soft subgrade will require the maximum thickness.

51. For a two-course road, the bottom course should consist of gravel varying in size from $\frac{1}{2}$ to $1\frac{1}{2}$ inches, the material to be evenly graded so as to give a fairly close mixture. The top course should consist of material from $\frac{1}{8}$ to $\frac{1}{2}$ inch in size, with the proper amount of binder added. For a three-course road, the bottom course may consist of particles as large as 3 inches, but the material should be so graded as to prevent the larger particles from forcing their way up through the

upper courses. The second course should consist of material from $\frac{1}{2}$ to $1\frac{1}{2}$ inches in size evenly graded, and the top course should be as specified for a two-course road. The proper depths of the various courses during construction can be maintained by lines stretched between stakes, or by blocks placed on the surface, and the material leveled off to the tops of the blocks. In both two-course and three-course roads the top course should not exceed 2 inches in thickness.

52. The gravel for each course as it is brought to the road is either dumped to one side of the roadbed and shoveled into place or is shoveled directly from the wagon into place. The gravel may also be spread directly on the roadbed when bottom-dump wagons are used; otherwise a dumping board should be used if it is necessary to dump the gravel on the roadbed. The material for the upper courses of the road should never be dumped directly upon the finished courses beneath, since this will result in the irregular compaction of the surface which can only be removed by harrowing or by continuous dragging during cold weather.

The gravel is distributed and given the proper shape by using either shovels and rakes or a toothed harrow and a road grader. When machines are used, a considerable length of gravel should be placed before shaping with the machines, as otherwise their use would not be economical. Each course, after it has been shaped up, is thoroughly rolled with a steam road roller. Rolling for each course should be continued until a firm and even surface is obtained. If any depressions occur during the rolling, they should be filled up with the same size of material as is used in the course being constructed.

The top course is usually puddled with water and binder during the process of rolling. The water when mixed with the binder causes it to produce cement-like qualities. Too much water, however, is detrimental, as it tends to wash out some of the finer binding material and to soften the subgrade.

Rolling should always progress from the sides toward the center so as to maintain the crown of the road. Ultimately the rolling should extend over the whole width of road, includ-

ing the shoulders. Gravel will compact to about 80 per cent. of its depth, loose measure. Hence, if a finished thickness of 8 inches is desired, it will be necessary to use a total depth of 10 inches, loose measure, in the various courses.

53. Maintenance of Gravel Roads.—It may take several months before a gravel crust is thoroughly compacted, no matter how well it may have been rolled during construction. During this period careful attention should be given to the road, and the ruts and hollows should be patched as soon as they are formed. In times of wet weather or of frost, a gravel surface will be soft and will rut very easily. The road drag is one of the best machines with which to maintain a gravel road. Where a road grader would unnecessarily disturb the surface, the road drag serves simply to smooth the road, fill in the hollows, and push just enough of the material toward the center to maintain the crown. Dragging will be required more frequently for the first year after the road is completed than at any other time.

As is the case in all road dragging, the work should be done when the surface is in a moist condition. As the road ages and becomes set, the road drags will not have any effect unless a prolonged period of rain has made the road very soft. All patching should be done when the road is in a wet condition, as then the new material added will bond to the old and will compact much better than when in a dry state. Great care should be taken not to get the patches too high, as such a procedure is liable to create a new hollow just beyond the one patched. The same size and kind of material should be used in making the patches as was used in building the courses.

BROKEN-STONE ROADS

PRINCIPAL VARIETIES

54. General Considerations.—A water-bound broken-stone road consists essentially of a layer of wearing surface composed of fragments of broken rock spread on the previously prepared natural soil, and consolidated to a firm, uni-

form surface by rolling with power rollers. Where broken stone is procurable at a reasonable price, it furnishes the best material, as regards efficiency, first cost, and expense of maintenance, for surfacing roads subjected to medium horse-drawn vehicular traffic. It affords an excellent foothold, is noiseless, does not offer much resistance to traffic, and is comfortable to use. In dry weather, however, a broken-stone surface is usually dusty unless the surface is treated with a palliative, that is, some material for temporarily laying the dust. Dust palliatives include water, sea-water, salt solutions, calcium chloride, tar and oil emulsions, light oils, and light tars. Detailed descriptions of these materials are given in *Highways*, Part 4.

55. To secure satisfactory results, certain essential points must be observed. The stone must be of suitable quality, and must be placed on a suitable roadbed. The bed must be thoroughly drained, and all disintegrated or worn-out material and vegetable matter must be removed. The subgrade must be brought to a uniform surface, free from hollows, and must be thoroughly consolidated. The voids in the mass of the broken stone must be eliminated by rolling and by adding fine dust; this dust should not be mixed with the stone, but should be applied after the stones have received a slight compaction by rolling. The broken stones should not be left loose to be compacted by the traffic, but should be consolidated by rolling with a roller of suitable weight to bring each piece of stone into close and firm contact with the adjacent pieces.

56. Classification of Broken-Stone Roads.—Roads constructed of broken stone are commonly classified as *macadam roads* and *telford roads*. These names are applied to distinguish two systems of construction originated, respectively, by John Loudon McAdam, an able Scotch road maker, who, in 1816, began advocating an improved system of road making, and Thomas Telford, an eminent English engineer, whose work as a builder of improved roads began in 1820. The appearance of the completed roadway is practically the

same in both systems, the distinguishing features being in the foundation.

McAdam's system consists essentially in spreading and compacting one or more uniform layers of suitable rock, broken into pieces of nearly uniform size, directly on an earth foundation that has been previously formed to the proper grade and cross-section and thoroughly compacted by rolling. A cross-section of a macadam road is shown in Fig. 13.

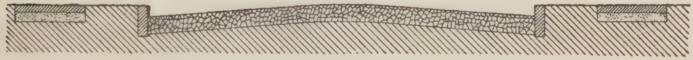


Fig. 13

Telford's system is much the same as McAdam's, except that the layer of broken stone forming the wearing surface is spread on a paved foundation. This paved foundation is formed by blocks of stone from 3 to 8 inches in depth, set close together on their broadest edges. The cross-section of a telford roadway is shown in Fig. 14. The blocks of stone are set on the earth foundation, and their sizes are graduated according to their position, as shown in the figure.

Fig. 14

Each of these systems has its place in the successful construction of roads. The choice depends entirely on the character and condition of the natural soil. If this is composed of clay, not easily drained, a telford foundation may be used; but, if the soil is easily drained, a foundation will not be required and the McAdam system will be found the cheaper and better adapted to the conditions.

BREAKING AND SCREENING THE STONE

57. Breaking the Stone.—The stone is broken to the required size in machines called rock crushers, of which two types are in common use, the *jaw crusher* and the *gyratory crusher*.

A **jaw crusher** is illustrated in Fig. 15, which shows a longitudinal section through the machine. The shafts *e*, *n*, and *o* are supported upon the frame *a*, which consists of a single casting of open-hearth steel surrounding all the moving parts. The moving parts comprise the swinging jaw plate *k* and the means for giving it the swinging motion. The stationary parts fastened to the frame comprise the stationary jaw plate *l* and the cheek plate *m*. Together, the parts *k*, *l*,

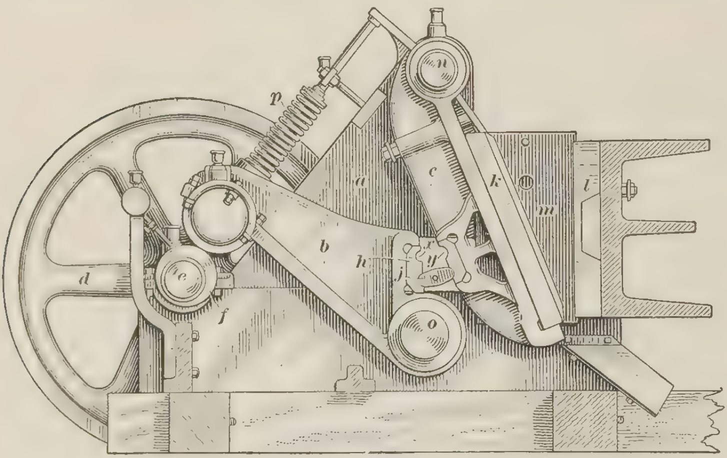


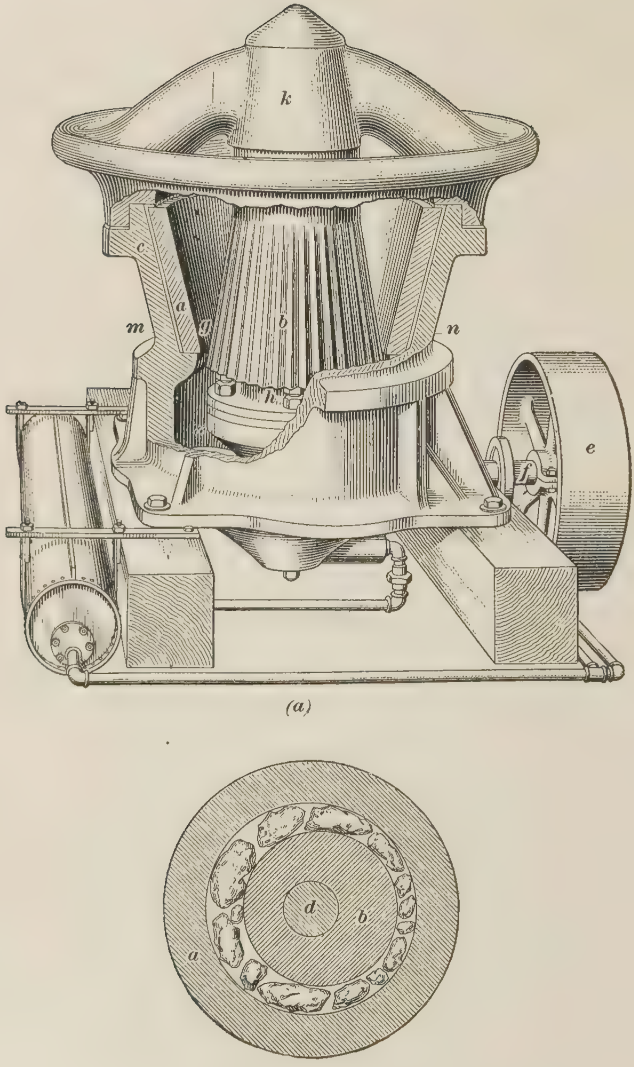
FIG. 15

and *m* form a hopper-like receptacle of which three sides are stationary and the fourth side *k* swings back and forth upon the jaw shaft *n*. In some types of jaw crushers the action is similar to the action of a pair of animal jaws, the stones dumped into the hopper-like space being broken between the jaw plates until sufficiently reduced in size to escape through the slot indicated at the lower end of the jaws. In the machine here illustrated the principle has been reversed, the swinging jaw plate being hinged at the upper, or feed, end. Thereby is obtained the advantage of a short oscillation of the upper part of the swinging jaw where the largest stones are broken up, and where, therefore, a short motion on a short lever arm and great pressure are especially desirable.

The swinging motion of the jaw is imparted to it by means

of a system of levers. The balance wheel *d* acts as a flywheel on the shaft which carries the eccentric *f*, and to this shaft the power is transferred by a belt drive from a steam engine, electric motor, or gasoline engine. The eccentric *f* imparts a swinging or oscillating motion to the lever *b*, the upper end of which is pressed against the eccentric *f* by means of the spring *p*, the lower end of the lever *b* being pivoted on a shaft *o*. By another lever action the adjusting plate *j* transfers the rocking motion of the lever *b* to the swinging jaw *c*. The width of the lower opening between the two jaws evidently determines the maximum size of the output of the crusher, because no stone can escape from the crusher that is too large to pass this opening. The width of this opening may be adjusted by substituting longer or shorter adjusting plates, and by changing the adjusting plate from its lower position, as indicated in the illustration, to a position *x y*, *x* and *y* being depressions provided for that purpose in the adjusting-plate seat *h*.

58. The **gyratory crusher** consists principally of two cones *a* and *b*, illustrated in Fig. 16 (*a*), which is a view of a small gyratory crusher with part of the outer casing broken away so as to expose the interior construction; in (*b*) is shown a horizontal section on the line *m n*. The hollow cone *a*, called the concave, is stationary and fastened to the shell *c*. The cone *b* is mounted on and revolves about a stationary shaft. A pulley *e*, driven by belt, transmits rotation to the cone *b*, by means of the shaft *f* and a set of bevel gears not shown in the drawing. If the revolving cone *b* were perfectly centered within the cone *a*, a fragment of rock introduced between the cones *a* and *b* would simply be rolled around between the two surfaces. But, as shown in view (*b*), the two cones are not concentric. It will be seen that the vertical shaft *d* is concentric with the concave cone *a*, but that the cone *b* is eccentrically mounted about the shaft. Therefore, when *b* swings rapidly around the shaft, the width of the space between *a* and *b* at any one place will constantly change, being now wider and filling up with stone, and then again becom-



(a)

(b)

FIG. 16

ing narrower, squeezing the stones to bits. The stone, reduced to the desired size, drops through the annular space *g* in view (*a*) into a bin or car below, or onto a conveyer that carries the crushed stone to the screens.

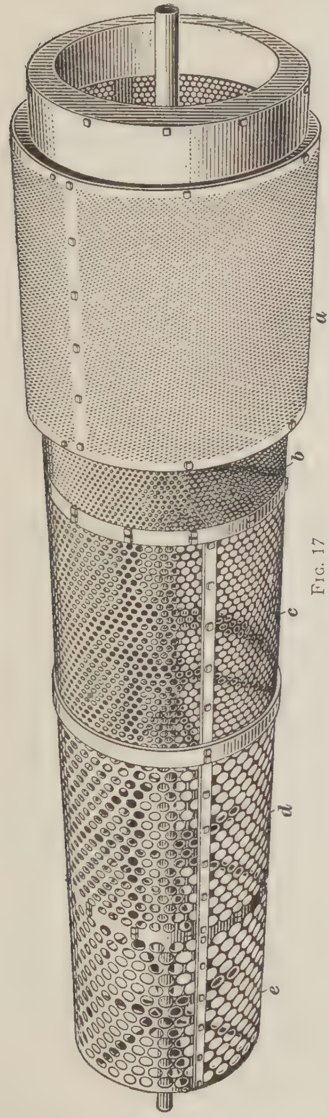


FIG. 17

59. Screening the Stone. The broken stone passes from the crusher to a revolving, perforated cylinder called a *screen.* The screens of a portable plant are commonly divided into three or four sections, the one in Fig. 17 having four sections. In this case the section *b* of the screen is fitted with a dust jacket *a* having $\frac{1}{4}$-inch openings so placed as to separate the dust from the stones that are passing through the first section. In the various bins situated under the screen are collected the sizes required. Thus, all dust is passing through the $\frac{1}{4}$-inch screen *a*, while the No. 1 size is passing through the $\frac{5}{8}$-inch screen *b*. No. 2 size is passing over screen *b* and through the $1\frac{1}{4}$-inch screen *c*. No. 3 size is passing over the screen *c* and through the $2\frac{1}{4}$-inch screen *d*. No. 4 size is passing over screen *d* and through the $3\frac{1}{2}$-inch screen *e*. Stones too large to pass through any of the holes are known as *tailings;* they pass from the screen through a chute beyond the bin for

No. 4 size. The rotary screen is usually inclined, or pitched, so that the material easily gravitates from one section to another.

SPECIFICATIONS FOR SIZES OF BROKEN STONE

60. Factors Affecting Grading of Stone.—Since nearly all of the broken stone used for highway construction is screened with a rotary screen, it should be noted that the speed at which the screen is revolved, the pitch, the length, and the size of the holes in the screen, all influence the grading of the stone into different sizes. The type of crusher used and the kind of rock crushed also influence the amount of the different sizes obtained. The width of the jaw opening of the crusher determines the maximum size of stone that will be obtained from crushing any rock. The stone will be broken into sizes varying from this maximum down to dust.

61. Methods of Grading Stone.—The sizes of broken stone are often stated as the longest dimensions of the product; for instance, as $1\frac{1}{2}$-inch stone, etc. A better method of describing the size of stone is to stipulate that it shall pass over a section of a screen having holes of one size and pass through a section of a screen having another size of holes, or that it shall pass a section of a screen having holes of one size and be retained on a section of a screen having another size of holes. The best method of specifying sizes of broken stone is the following, as adopted by the Special Committee on Materials for Road Construction, of the American Society of Civil Engineers:

The broken stone shall consist of one product of the operation of a stone-crushing and screening plant, without recombining or mixing, and shall conform to the following mechanical analysis, using laboratory screens:

Passing............inch screen (having smallest holes selected), from ....to............per cent.

Passing............inch screen (having next to largest holes selected), from............to............per cent.

Passing............inch screen (having largest holes selected), from ....to............per cent.

In this form of specification an attempt is made to cover in the mechanical analysis only the limits of the smallest and largest particles. No attempt is made to secure a carefully graded aggregate, but simply a product suitable for the type of road or pavement in question.

An engineer should base the selection of screens to be used in the specification for a given product of broken stone, on the results of mechanical analyses of many similar products obtained from portable and stationary crushing and screening plants which supply the locality in which the specification is to be used.

62. Sizes of Broken Stone Used in Different Courses.—Broken-stone roads are ordinarily built in two or three courses. The larger-size products of the crusher are generally used in the first, or foundation, course. Gravel and slag are sometimes substituted for broken stone in the foundation course. The size of stone for this course varies from 1 to 3 inches in the longest dimensions. The second course is composed of stone slightly smaller, ranging from 1 to 2 inches or from $\frac{1}{2}$ inch to $1\frac{1}{4}$ inches in the longest dimensions. The top course consists of screenings varying from about $\frac{1}{2}$ inch down to dust.

63. Thickness of Courses of Broken Stone.—The necessary thickness of the covering of broken stone depends on the nature of the foundation, the thoroughness of the drainage, the completeness of the binding, and the character of the traffic to be sustained. Less thickness will be required for light travel than for heavy travel. A covering well bound together need not be so thick as an imperfectly bound covering. A firm, thoroughly drained foundation does not require so thick a covering as a less perfect foundation. The thickness of the covering of broken stone should not be less than 4 inches, and a thickness greater than 12 inches is seldom required. McAdam considered 10 inches of well-compacted broken stone on a solid, well-drained earth foundation sufficient for a roadway sustaining the heaviest traffic. A thickness of from 6 to 10 inches is generally considered sufficient.

CONSTRUCTION OF BROKEN-STONE ROADS

64. Preparing the Subgrade.—The earth foundation of the roadway, which is sometimes called the *roadbed*, should be formed to the proper grade and cross-section and thoroughly compacted by rolling before the covering or surface material is put on. When the foundation is finished, its surface, which is commonly called the *subgrade*, should be at a distance below the grade line equal to the intended thickness of the covering material. The earth foundation should slope from the center each way toward the gutter, its form being the same as that of the cross-section of the road surface.

Where the surface of the completed roadway is not materially higher than the natural surface of the ground, the road-

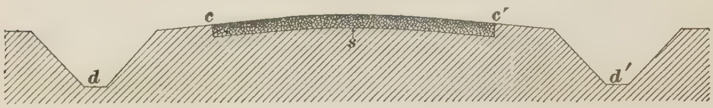


Fig. 18

bed is formed by excavating a trench of the proper width and depth to receive the covering material. This is shown in Fig. 18, which is the cross-section of a macadam road for which the drainage is effected wholly by the deep side ditches d and d'. The excavation for the covering material is $c\ s\ c'$.

65. Before the covering of stone is applied, the foundation should be thoroughly compacted by rolling with a heavy roller. After a thorough rolling, the surface will be more or less uneven. The irregularities in the surface must be removed by cutting down the high places and filling in the hollows, after which the rolling is resumed. This process is continued until a firm and even surface is obtained. On the foundation thus prepared, the covering material is spread.

66. Applying the Broken Stone.—The broken stone is hauled on the roadbed in wagons or other vehicles, dumped, and spread broadcast over the bed by the use of stone forks,

and is brought to a uniform thickness by the use of rakes. Sometimes carts called *spreading carts* are employed, which place the stone where required and automatically spread it in layers of any required depth.

To secure uniformity of thickness, grade stakes are placed at suitable intervals along the margin of the road. To gauge the thickness of a layer of stone, wooden cubes, made equal to the depth of a layer, are sometimes placed at intervals across the roadway, the cubes being taken up and moved along as the work progresses. With this method, however, if there are any irregularities in the subgrade or in the foundation course, they will be carried up to the finished surface. A better method of regulating the depths of the different layers is to set strings longitudinally at the proper elevation at the sides and center of the roadway. In this manner the elevations are always tied in with the finished grade and any irregularities can readily be corrected as they occur.

67. Rolling.—After the layer of stone has been spread for some distance, and to the full width of the roadway, the rolling is begun. The roller should be preceded by a sprinkling cart, which distributes water over the layer of stones. The rolling is commenced at one edge of the road, and is carried on opposite sides alternately, in such a manner that the strip first rolled is overlapped at each trip, until the center is reached. As the rolling progresses, the hollows that are formed are filled with stone. The rolling is continued until there is no perceptible motion among the stones. A second course or layer is then applied, and the process of rolling and sprinkling is repeated.

The weight of the roller and the manner of its application affect, to a certain extent, the enduring qualities of the stone. To secure the best results, the weight of the roller must be determined by the character of the stone to be compacted. If the stone is soft and friable, as some limestones, a roller weighing about 5 to 9 tons should be employed, as a heavier roller will crush the stone to dust. For the harder stones, as trap, a roller weighing from 10 to 15 tons may be used.

68. In some specifications it is stated that the voids in the foundation course shall be filled with stone screenings, sand, or gravel, the fine binding material to be thoroughly swept in, watered, and rolled, so that no surplus material remains on the surface of the foundation course. This method of construction provides a firmer foundation than where the voids between the stones are not so filled. The same treatment is also frequently used to facilitate the rolling of the foundation course where the stone is of such a character that it will not readily compact under the action of the roller.

When the last course has been properly compacted, the *binder* is spread over its surface to a depth of $\frac{1}{2}$ or $\frac{3}{4}$ inch, and sprinkled; the rolling is repeated and continued until the consolidation is complete. The finished surface should have a crown of from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch to the foot.

69. Binder.—The stone dust spread on the surface of the broken stone is called the binder. The object in using a binder is to fill completely the voids that remain after the roadway has been compacted with the roller, and which no amount of rolling will entirely eliminate. The amount of binder must be only slightly in excess of that required to fill the voids; a larger quantity than needed for this purpose will be injurious. The voids in a well-compacted mass of stone amount to about 25 per cent. of the mass, and a corresponding amount of binder must be used to fill them. The amount of water used must be moderate; it is used simply as a lubricant to assist the compacting of the stone. A large quantity will cause the stone to be forced into the roadbed, forming a weak and defective road that under traffic will produce mud and dust.

MAINTENANCE

70. Essential Requirements.—The following are the essential requirements that must be complied with in maintaining broken-stone roads. At all times the surface of the road should be kept smooth. This enables the road to shed

water more readily and eliminates shocks which would result from the traffic where the surface is uneven. Any hollows or pot holes that develop in the surface should be repaired as soon as formed. Particular attention should be given to eliminating the ruts, since any depressions in the surface hold water and are enlarged very rapidly by the action of traffic. Broken stone of the same size as is used in the upper course should be used in filling the depressions and ruts.

In France and England it has been found that, in repairing pot holes, the best results are obtained if the holes are cut out on the lines of a square or rectangle that is of sufficient area to include the depression, the sides to be cut through for the full depth of the wearing course. The stone is replaced, carefully tamped, filled with screenings, and puddled, or it is incorporated with some bituminous material either before or after placing.

Rolling in the spring of the year when the road is soft will be of great help in providing a smooth surface for the remainder of the season. An excess of dust or mud on the surface should be removed, since dust is not only very objectionable from the standpoint of comfort to the traffic, but when wet it forms mud which keeps the surface of the road in a moist condition, sometimes for a long period. On the other hand, when the upper course of stone presents a mosaic surface, sand, stone screenings, or other binding material should be spread on the surface to prevent raveling.

71. Resurfacing.—When the road becomes so badly worn that it is impossible economically to keep it in good condition by the ordinary methods of maintenance, resurfacing is necessary. Unless an average depth of stone of about 3 inches is to be added, the old broken stone surface should be picked or scarified so that the new stone will bond with the old. The new stone is added wherever required to bring the surface to the proper shape, and the surface is then thoroughly rolled and puddled, as in constructing a new road.

BITUMINOUS SURFACES ON BROKEN-STONE AND GRAVEL ROADS

BITUMINOUS MATERIALS AND THEIR PROPERTIES

72. Composition and Properties of Bituminous Surfaces.—Bituminous surfaces consist of superficial coats of bituminous materials with or without the addition of stone or slag chips, gravel, sand, or materials of a similar character. It is evident, therefore, that the reapplication of oils and tars when used primarily for dust prevention may result in the formation of bituminous surfaces. Hence, the line of distinction between treatments with dust layers and the construction of bituminous surfaces is not clearly defined. The methods of construction usually considered under the heading of bituminous surfaces are confined to those methods that ordinarily result in a bituminous surface with a life of at least 1 year.

73. A properly constructed bituminous surface on a broken-stone or gravel road is impervious to water and is easily cleaned. It increases the durability of the road, yields no dust due to abrasion of the roadway surface, and permits reduction in the amount of crown. When asphaltic materials are used, the noise caused by horse-drawn vehicles is comparable to that of wood-block pavements subjected to the same kind of traffic, while bituminous surfaces constructed with a thin coat of tar give forth much more noise, in some cases comparable to that emanating from the impact of horse-drawn vehicle traffic on sheet-asphalt pavements.

74. Bituminous Materials Employed.—The different kinds of bituminous materials used are asphaltic oils, asphalts, crude and refined water-gas tars, crude and refined coal-gas tars, combinations of refined tars, and combinations of refined tars and asphalts. Bituminous materials that require from 2 to 6 weeks to harden to such an extent that the surface material will not be picked up or indented by the wheels of vehicles, should not be used. Bituminous surfaces

constructed with suitable refined coal tars, water-gas tars, combinations of asphaltic materials and refined tars, or cut-back asphalts, using from $\frac{1}{4}$ to $\frac{1}{2}$ gallon per square yard and a thin covering of stone chips, have set satisfactorily within 24 to 48 hours.

CONSTRUCTION AND MAINTENANCE

75. Preparing Surface of Roadway.—Before a bituminous surface is constructed on a broken-stone or gravel road, all depressions, pot holes, ruts, or other irregularities should be filled with thoroughly compacted bituminous-coated stone, so that the whole surface of the roadway is even.

In order to secure a good bond, the roadway surface must be bone dry and clean when the bituminous material is applied. All surplus dust must be removed, so that the larger pieces of broken stone of the roadway surface are exposed without breaking the bond. This cleaning process is usually accomplished by the use of horse sweepers and fine brooms, or with coarse brooms and fine brooms. If there is caked mud on the surface of the roadway, wet brushing will prove advantageous. The character of the cleaned surface will be affected by the method that was used in the original construction of the roadway. If large-size stone varying from 1 to $2\frac{1}{2}$ inches was used for the top course of a broken-stone road, and the stone is hard and tough, the desired clean mosaic surface may be easily secured. If the top course of a broken-stone road has been constructed of a crusher product varying in size from $\frac{1}{4}$- to $1\frac{1}{4}$-inch material, it will be very difficult to secure a clean surface.

76. Maintenance.—The life of a bituminous surface and its economical use depend primarily upon traffic conditions, the method of construction, and the nature of the bituminous material used. With the heavier grades of bituminous materials adaptable for this work, if the road is subjected to a normal traffic for which the method and material are economical and suitable, retreatment is necessary every 1 or 2 years.

Retreatments can generally be accomplished by using a smaller amount of bituminous material, usually about half the amount used in the first treatment. The same care should be taken in preparing the road surface as is done in the original treatment. Continuous repairing methods are, of course, productive of the most satisfactory results. As it is difficult to barricade a road after small repairs have been made, a method should be used that will prevent displacement of the road metal employed in patching.

APPLICATION OF BITUMINOUS MATERIAL

77. Principal Methods of Distribution.—Bituminous material may be distributed on roads by either of the following methods: (*a*) Flow by gravity, and (*b*) mechanical pressure. It is claimed that the use of mechanical pressure aids in cleaning the surface of the roadway, that it enables the material to be evenly applied and in small amounts per square yard, and that satisfactory adhesion is obtained between the bituminous material and the surface of the roadway. In gravity distribution, it is possible by means of subsequent brushing to distribute uniformly $\frac{1}{4}$ to $\frac{1}{5}$ of a gallon per yard of many of the bituminous materials used for the construction of bituminous surfaces, and in some cases the adhesion to the road material is as good as when the surface material is applied under pressure. As a general rule, from $\frac{1}{4}$ to $\frac{1}{2}$ gallon per square yard is used for the first treatment. In some cases, however, as small an amount as $\frac{1}{8}$ of a gallon per square yard is employed. The amount applied per treatment depends upon the kind of bituminous material, the charter and condition of the surface, and the details of the method of application.

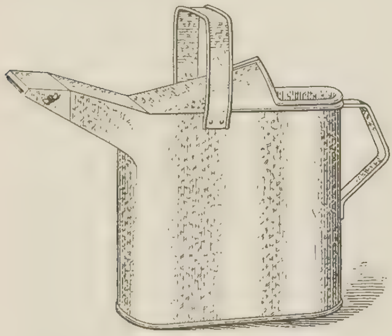


FIG. 19

78. Gravity Distributors.—The appliances used for distribution of the material by gravity are: Cans, tanks with hose attached, and distribution machines.

Pouring Cans.—The molten material may be poured on the road from a pouring can. Of these there are several varieties, of which the can with a flattened spout, shown in Fig. 19, has given good satisfaction; but it is evident that even with the best of cans it is very difficult to secure uniform distribu-

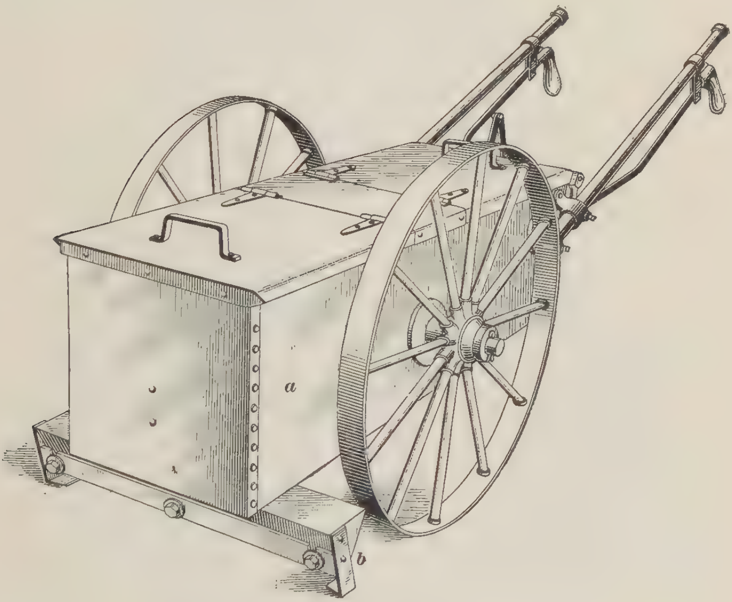


Fig. 20

tion of the material. However, if the fluid layer is immediately subjected to a vigorous brushing with fiber push brooms, very satisfactory surfaces can be obtained.

Hand-Drawn Gravity Distributors.—The advantages of hand-drawn distributors, Fig. 20, over pouring cans are the more uniform distribution of materials, the elimination, to a certain extent, of the personal equation, more rapid work, and the practicability of keeping the bituminous material at a higher and more even temperature. In the machine shown

in Fig. 20, the bituminous material flows by gravity from the tank *a* through the horizontal slot *b* in the form of a sheet.

Tanks With Hose Attached.—If a tank from which the bituminous material flows by gravity through a hose and nozzle onto the road is used, brushing is necessary to secure satisfactory distribution.

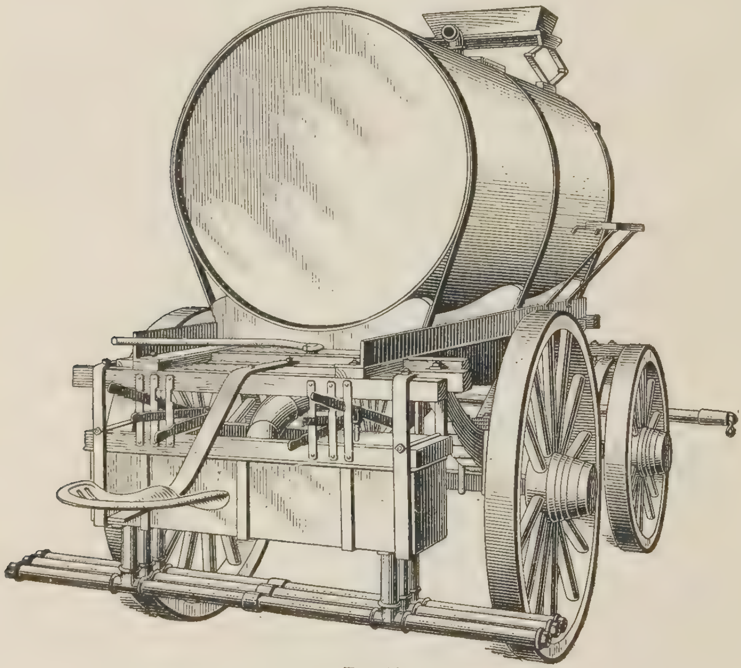


Fig. 21

Machines With Distributing Apparatus.—Watering carts were first used in the United States for distributing the light oils and tars for suppressing the dust. Practically all of the modifications have consisted in substituting for water sprinklers one or more horizontal pipes pierced with small holes. These pipes are attached to the outlet pipe of the tank and are placed parallel to the back axle at the rear of the tank, as shown in Fig. 21. The pipes are usually about the same length

as the gauge of the rear wheels. The material flows through these pipes in small vertical streams onto the road surface. Hence, in distributing small quantities, the road surface may not be entirely covered with the material. In some American machines, the material flows from pipes onto a flash board and from the board to the surface of the roadway in the form of a sheet. The general practice in Europe in using machines of this type is to follow the distribution by brushing the material into the road. This is done either by hand brooming or by brooms attached directly behind the distributor.

79. Pressure Distributors.—The various types of distributing machines operated by pressure may be grouped in the following subdivisions: Hand-drawn distributors; pressure tanks to which are attached hose and spraying devices or horizontal distributing apparatus; and machines equipped with mechanical power pumps between the tank and the distributing apparatus.

Hand-Drawn Pressure Distributors.—In the European machines, the material is pumped from the tank through a length of flexible hose to the outlet end of which is fixed an iron pipe fitted with one or more nozzles. The nozzle is of such a form that the material is thrown in a fine cone-shaped spray. In one type of American machine, the heated material is pumped into the distributor and applied to the roadway surface by pressure from a tank of compressed air.

Pressure Tanks.—Pressure tanks consist of steel tanks equipped with either a flexible hose and attached nozzle or a system of pipes equipped with nozzles. The tanks are hauled by a steam roller, which furnishes the steam for the required pressure.

Pressure Distributors Equipped With Mechanical Power Pumps.—The distributing devices of the distributors operated by pumps are alike in having horizontal pipes fitted with nozzles. The machines differ somewhat in the way the pressure is obtained and applied. Pumps run by a sprocket-drive attachment on the rear axle, by steam, or by gasoline, are utilized. Horses and steam rollers are used for hauling.

Some distributors are mounted on motor trucks, as shown in Fig. 22.

80. Applying the Covering.—The superficial coat of bituminous material is usually covered with either coarse sand, fine gravel, or stone chips, varying from $\frac{1}{8}$ to $\frac{1}{2}$ inch in largest dimension. The amount of sand, stone chips, or gravel

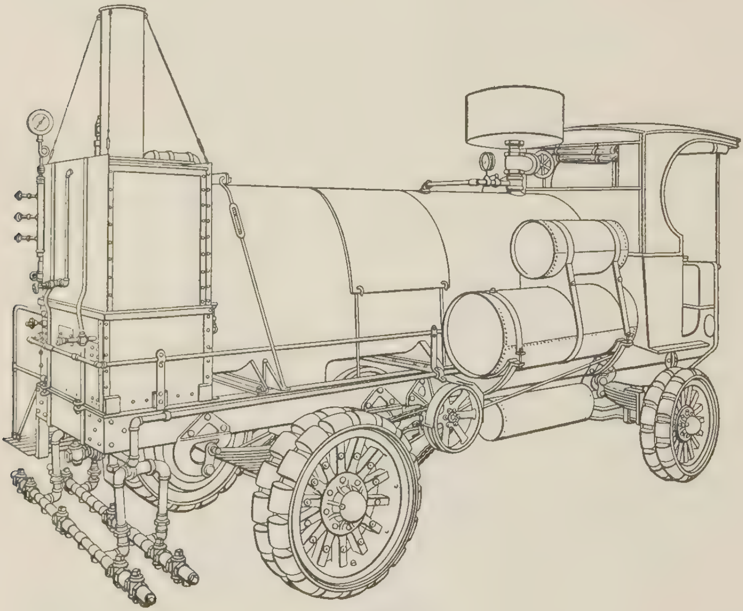


FIG. 22

used per square yard depends upon the quantity and kind of the bituminous material. From 7 to 15 pounds per square yard has been used satisfactorily. This top dressing is distributed by hand and machine methods. In the machines employed for this purpose, the mineral matter falls on a revolving cone beneath the body of the wagon and is thus uniformly spread over the surface.

BITUMINOUS-MACADAM PAVEMENTS

GENERAL CHARACTERISTICS

81. Definitions.—A *bituminous-macadam pavement* is one having a wearing course of macadam with the interstices filled with a bituminous binder applied by the penetration method. The penetration method consists of pouring or grouting the bituminous material into the upper course of the road material before the binding of the latter has been completed. In connection with the interpretation of this definition, it should be noted that the term macadam refers to a road crust composed of stone or similar material broken into irregular angular fragments compacted together so as to be interlocked and mechanically bound to the utmost possible extent.

82. Advantages.—Many bituminous pavements constructed by penetration methods possess the following advantages: Suitability for horse-drawn as well as motor-car travel; freedom from dust when in exposed localities; low external and internal wear of road metal; low cost of cleaning, watering, and in many cases, of repairs; imperviousness and a certain degree of density of the wearing course; noiselessness and low traction with certain types of bituminous materials; very good sanitary qualities.

83. Bituminous Materials Employed.—The bituminous materials used in the construction of bituminous pavements built by penetration methods, include asphalt cements, heavy asphaltic oils, refined water-gas tars, refined coal-gas tars, combinations of refined tars, and combinations of refined tars and asphalts.

METHODS OF CONSTRUCTION AND MAINTENANCE

84. Fundamental Features.—In the construction of bituminous macadam pavements it is desirable to obtain the following results: (1) A stable wearing course consisting of broken stone or similar material thoroughly rolled so that it

will be well compacted and keyed together and the several sizes of material will be uniformly distributed; (2) a uniform distribution and penetration of the bituminous material within the upper 2 or 3 inches of the crust.

Several methods of construction have been devised with a view to meeting the prerequisites mentioned. Because, however, of the lack of uniformity in the density of the wearing course of broken stone and in the amount of bituminous material applied per square yard by the many methods employed, uniform incorporation of the binder with the road metal is difficult to secure.

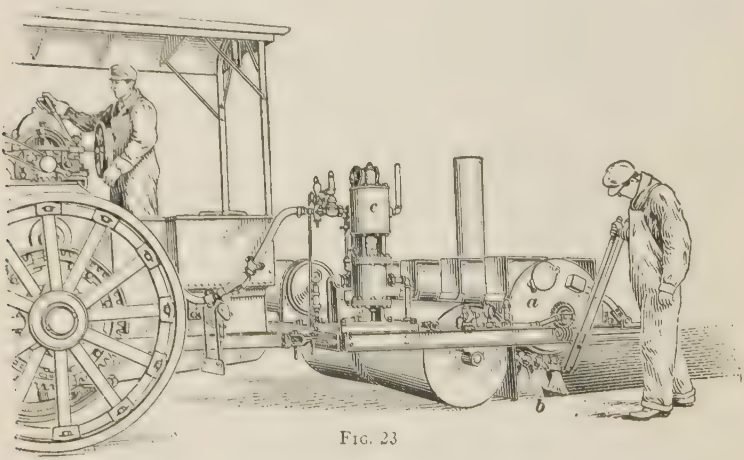


FIG. 23

85. The pavement is generally built in two or three courses, the foundation course being from 4 to 8 inches thick after rolling, and the top course from 2 to 3 inches after rolling. The foundation is usually composed of the product of a crusher which passes over a screen with $1\frac{1}{2}$-inch circular holes and through a screen with $2\frac{1}{2}$-inch circular holes, or over and through screens having openings of similar dimensions. The foundation should be thoroughly compacted with a 10- to 15-ton roller before the construction of the wearing course. The bituminous material is distributed by hand pouring cans, gravity distributors, or pressure distributors.

The pressure machine shown in Fig. 23 was designed for the construction of bituminous-macadam pavements. The tank *a* is filled with bituminous cement, which is forced through the nozzles *b* by compressed air from the compressor *c*.

86. There are several methods of roadway construction, depending on the size of the broken stone employed, the number of stone courses, the kind and number of coats of bituminous cement applied, and the kind of filling material employed. Six of the principal methods will now be described.

87. First Method of Construction.—In this method, the road metal of the wearing course consists of broken stone, ranging in size from a product the particles of which vary from $\frac{1}{2}$ to $1\frac{1}{2}$ inches in longest dimensions to a product passing over a $1\frac{1}{2}$-inch and through a $2\frac{1}{2}$-inch screen. After the wearing course is laid, the bituminous cement is applied, either before or after the broken stone is rolled. To secure the best results, the wearing course should be thoroughly rolled before the application of the bituminous cement, in order to secure a well compacted and stable course of broken stone, mechanically interlocked and bound together. After the application of the bituminous cement, a coat of mineral matter, such as crushed granite, trap, limestone, field stone, etc., should be spread over the surface of the course and rolled. The total amount of bituminous cement used in this method varies from $1\frac{1}{2}$ to $2\frac{1}{2}$ gallons per square yard.

88. Second Method of Construction.—In case the metalling of the wearing course is a uniform product that will pass over a 1- or $1\frac{1}{2}$-inch screen and through a $2\frac{1}{2}$-inch screen, usually the voids in the upper part of the wearing course are filled after the bituminous cement is applied. For traffic that is medium or heavy in weight and amount, the best results have been secured by thoroughly rolling the road metal, thus obtaining maximum interlocking of the particles and thereby securing the highest degree of stability practicable by this method. The bituminous cement is applied in an amount varying from $1\frac{1}{2}$ to 2 gallons per square yard, after which a

layer of $\frac{3}{8}$-inch stone chips or a product similar to one passing over a $\frac{1}{2}$-inch and through a 1-inch screen is spread and thoroughly rolled. Usually the surface is then broomed with stiff brooms to remove the excess loose broken stone, and another coat of bituminous cement, from $\frac{1}{3}$ to 1 gallon per square yard, is applied, covered with a layer of stone chips or pea gravel, and rolled.

89. Third Method of Construction.—This method is often used when the road metal composing the wearing course varies in size from 2 to $3\frac{1}{2}$ inches or from $2\frac{1}{2}$ to 4 inches. After lightly rolling the wearing course, coarse sand, stone chips, or pea gravel is spread and broomed until the voids of the metal are partly filled. Usually the road metal is again lightly rolled and any surplus material is broomed off the surface. The bituminous cement is then applied, using from $1\frac{1}{4}$ to 2 gallons per square yard. This coat is covered with a layer of pea gravel, screened stone chips, or larger broken stone, and thoroughly rolled. Sometimes a *seal coat*, or final superficial application, of from $\frac{1}{2}$ to 1 gallon of bituminous cement is used with this method.

90. Fourth Method of Construction.—A bituminous-macadam pavement called *Pitchmac* has been adopted as a standard type by the Road Board of England. It is constructed on a foundation of stone. The wearing course of broken stone varies from 2 to $4\frac{1}{2}$ inches in depth, depending upon traffic conditions. If the wearing course is from 2 to 3 inches in thickness, it is constructed in one layer, and if from 4 to $4\frac{1}{2}$ inches, in two layers. The single layer, or the upper layer in case two layers are used, is composed of broken stone ranging in size from $1\frac{1}{4}$ to $2\frac{1}{2}$ inches. After thorough rolling, the bituminous cement is applied to the single layer or to each of the layers of the two-layer wearing course. The bituminous compound used in England consists of hot sand mixed with tar pitch. From $1\frac{1}{4}$ to 2 gallons per square yard are used for the one-layer wearing course and from $3\frac{1}{4}$ to $3\frac{1}{2}$ gallons for two layers. To assist in completely filling the voids, chips varying in size from $\frac{3}{8}$ to $\frac{3}{4}$ inch are applied during

the rolling of the bituminous-grouted layer. This type of pavement has been used to a limited extent in Massachusetts.

91. Fifth Method of Construction.—When the metal of the wearing course is of a large and uniform size, another method employed is to place a layer of sand $\frac{3}{4}$ inch thick on the bottom course, the voids of which have been filled. The bituminous cement is then distributed on this layer, about 1 gallon per square yard being used. The upper course of metalling is immediately placed on this course and rolled. Continued rolling forces the material of the upper course down and draws the bituminous material, sometimes called *mastic*, up into the voids. A coat of bituminous cement, about $1\frac{3}{4}$ gallons per square yard, is then applied to the surface of the upper course. A layer of $\frac{3}{8}$-inch stone, $\frac{1}{2}$ to $\frac{3}{4}$ inch thick, is spread over this and rolled. The work may stop here or may be carried a step further by brooming off the excess $\frac{3}{8}$-inch stone, and then applying another coat of bituminous cement, about $\frac{1}{2}$ gallon per square yard, adding a layer of screened stone chips, and rolling.

92. Sixth Method of Construction.—In some cases, when heavy asphaltic oil has been used for the bituminous cement, the following method has been employed. Upon a course of broken stone, prior to rolling, about $\frac{1}{2}$ gallon per square yard of asphaltic oil is distributed. The course is then harrowed, after which the second application of about $\frac{1}{2}$ gallon per square yard is made. The course is next thoroughly rolled, and during the rolling screenings are spread. In some cases the pavement is finished by a third application of $\frac{1}{2}$ gallon of oil per square yard, then screened and rolled. In other cases, the third treatment is followed by a fourth application of oil, from $\frac{1}{4}$ to $\frac{1}{3}$ gallon per square yard being used.

93. Maintenance of Bituminous-Macadam Pavement.—Where either an uneven distribution or an uneven penetration has caused an excess of bituminous material to exude on the surface of a bituminous-macadam pavement, the spots should be covered with sand, gravel, or stone chips.

Places that disintegrate should be cut out with perpendicular sides and refilled either with a mixed aggregate or by building the hole up with successive layers of road metal and bituminous material. The former method, however, gives the better results. Light oils and light tars should never be used for repairing holes, as the patches thus formed will not be stable and hence will soon be displaced by traffic. At varied intervals it is economical to renew the bituminous surface on the pavement by using from $\frac{1}{4}$ to $\frac{3}{4}$ gallon of the proper type of bituminous material per square yard.

BITUMINOUS-CONCRETE PAVEMENTS

DEFINITION AND CLASSIFICATION

94. Definition.—Bituminous-concrete pavements comprise all those having wearing courses in which the aggregate is mixed with bituminous cement, except those in which the aggregate consists entirely of sand or other fine material whose particles have diameters less than $\frac{1}{4}$ inch. All of the advantages resulting from the construction of bituminous surfaces on macadam and gravel roads and of bituminous-macadam pavements are characteristic of bituminous-concrete pavements. In addition, they are usually more stable and durable than bituminous-macadam pavements.

95. Classification.—Bituminous-concrete pavements may generally be grouped into the following classes adopted by the Special Committee on Materials for Road Construction, of the American Society of Civil Engineers.

Class A: A bituminous-concrete pavement having a mineral aggregate composed of one product of a crushing or screening plant.

Class B: A bituminous-concrete pavement having a mineral aggregate composed of a certain number of parts by weight or volume of one product of a crushing or screening plant, and a certain number of parts by weight or volume of

sand, broken-stone screenings, or similar material, with or without a filler.

Class C: A bituminous-concrete pavement having a predetermined, mechanically graded aggregate composed of broken stone, broken slag, gravel, or shell, with or without sand, Portland cement, fine inert material, or combinations thereof.

METHODS OF CONSTRUCTION

96. Foundations.—For medium and heavy commercial traffic, cement-concrete foundations should be employed for pavements of Classes *A* and *B*; for light-weight traffic, however, satisfactory results have been secured by using well-compacted broken-stone foundations, varying from 4 to 8 inches in depth. Generally, Class *C* pavements should be built on cement-concrete foundations.

97. Bituminous Cements.—The bituminous materials used in construction of bituminous-concrete pavements are asphalt cements, refined water-gas tars, refined coal tars, combination of tars, and combination of tars and asphalts.

98. Bituminous-Concrete Pavement—Class A. Broken stone, because of the satisfactory mechanical bond secured, makes the most suitable aggregate for Class *A* bituminous concrete, although pavements constructed with gravel have proved satisfactory for light traffic where great care has been taken in the selection of the gravel and in the construction of the pavement.

The broken stone should be clean, rough-surfaced, sharp-angled, of compact texture, and of uniform grain. If the pavement is to be subjected to medium traffic, the broken stone used for the construction of the wearing course should show a loss by abrasion of not more than 3.5 per cent. and its toughness should be not less than 13.

A mineral aggregate that will comply with the following mechanical analysis will produce satisfactory results: All the material to pass a $1\frac{1}{4}$-inch screen; not more than 10 per cent. nor less than 1 per cent. to be retained on a 1-inch screen;

not more than 10 per cent. nor less than 3 per cent. to pass a $\frac{1}{4}$-inch screen.

The amount of bituminous cement used depends upon the kind of road metal and the bituminous material, the character of the aggregate, and the climatic conditions. For the product of broken stone heretofore mentioned, it has been found that bituminous mixtures should contain between 5 and 8 per cent. by weight of bitumen.

99. Bituminous-Concrete Pavement—Class B. Specifications for Class *B* type of pavement generally stipulate that so many parts of broken stone and so many parts of sand or other fine material are to be mixed with a certain amount of bituminous cement. By the use of this specification under expert supervision, it has been found practicable to secure a fairly well-graded aggregate. In many cases, however, the mixture used has contained an excess of broken stone with insufficient fine material to fill the voids therein, while in other cases it has contained an excess of sand in which the broken stone existed as isolated particles.

100. Bituminous-Concrete Pavement—Class C. Specifications for Class *C* type of pavements usually call for mechanically graded aggregates of broken stone or gravel, either alone or combined with sand, with or without other fine material. The bituminous-concrete pavements of this type that have been most extensively employed are known as *Topeka*, *Asphalt Blocks*, *Bitulithic*, and *Warrenite*.

Since 1911 many thousands of yards of pavements have been laid under the so-called *Topeka specifications*. A decree was signed in 1910 by certain city officials and representatives of the Warren Brothers Company, owners of the Bitulithic and Warrenite patents, allowing the use of the Topeka mineral aggregate, as given in Table II, without danger of litigation proceedings.

101. Many unsatisfactory pavements have resulted from the unintelligent use of the grading of the material given in Table II. It has, therefore, been found necessary, in order

TABLE II

ORIGINAL GRADING OF MINERAL AGGREGATE FOR TOPEKA PAVEMENT

Name of Substance	Size of Sieve Passed Through	Amount Per Cent.
Bitumen		7 to 11
Mineral aggregate	200 mesh	5 to 11
Mineral aggregate	40 mesh	18 to 30
Mineral aggregate	10 mesh	25 to 55
Mineral aggregate	2 mesh	less than 10

to secure successful results, to define specifically the character of the sand or fine material that shall be employed in order to secure a satisfactory grading. Many specifications now cover the sand grading with almost the same care as in the case of sand-grading requirements for sheet-asphalt pavements. In order to encourage the use of a more satisfactory grading for this type of pavement, the American Society of Municipal Improvements in 1915 recommended the adoption of the grading given in Table III.

TABLE III

MODIFIED GRADING OF MINERAL AGGREGATE FOR TOPEKA PAVEMENT

Minimum Sizes of Sieve Passed Through	Maximum Sizes of Sieve on Which Retained	Amount Per Cent.
200 mesh		7 to 10
80 mesh	200 mesh	10 to 20
40 mesh	80 mesh	10 to 25
20 mesh	40 mesh	10 to 25
8 mesh	20 mesh	10 to 20
4 mesh	8 mesh	15 to 20
2 mesh	4 mesh	5 to 10

102. The patented pavements, **Bitulithic** and **Warrenite,** have aggregates usually composed of broken stone or gravel, sand, and bituminous cement. The maximum size of stone is about one-half the thickness of the wearing course. Specifications require that the several sizes composing the aggregate shall be so combined as to give a dense bituminous concrete. As stated by George C. Warren, President of the Warren Brothers Company, "Bitulithic is designed to meet the conditions generally prevailing on city streets, and Warrenite is to meet such conditions as may arise on country roads so as to meet the physical and economic conditions and public demands as to cost."

The methods of handling the materials for these pavements are described further on.

MANUFACTURE, LAYING, AND MAINTENANCE

103. Wearing Course.—The details of the manufacture and laying of the wearing course will depend to a certain extent upon the type of bituminous-concrete pavement employed and the kind of bituminous cement used. There are, however, certain fundamental methods that are common to all classes of construction.

The mineral aggregate, consisting of one or more grades of broken stone, sand, or similar materials or combinations thereof, is carefully weighed, or its volume determined, and is mixed with a given weight or volume of bituminous cement in a type of mixer suitable for the particular class of aggregate and kind of bituminous cement employed. In the best methods of construction, the mineral aggregate, before it is placed in the mixer, is heated to a temperature that will dry it and allow the component particles to be readily coated with the hot bituminous cement. The amount of bitumen employed varies from 5 to 8 per cent. for bituminous-concrete pavements that have aggregates composed of one product of a stone-crushing plant, to 7 to 11 per cent. for Topeka bituminous-concrete pavements. After the mineral aggregate is thoroughly coated in the mixer, it is transported by

wheelbarrows, wagons, or trucks, and deposited on dumping boards which have been placed upon the prepared foundation. The bituminous concrete is placed by shovels and raked to an even thickness and is then thoroughly compacted by rolling. Many engineers prefer to use a tandem roller, as it is practicable, under average conditions, to shape up the wearing course more satisfactorily with this than with a three-wheeled roller. The weight of the roller varies from 7 to 8 tons for Topeka bituminous concrete, and from 9 to 12 tons for other types of bituminous-concrete pavements.

104. Seal Coat.—After the bituminous concrete has been thoroughly compacted and the surface is dry and clean, a seal coat is applied on the surface of many types of pavements. The bituminous cement is distributed by pressure distributors, or by use of pouring pots or hand-drawn gravity distributors followed by brushing or squeegeeing. The amount of seal coat varies from about $\frac{1}{8}$ of a gallon per square yard, if used on Topeka bituminous-concrete pavement, to from $\frac{1}{2}$ to 1 gallon per square yard for a bituminous-concrete pavement having an aggregate composed of one product of a stone-crushing plant. As soon as practicable a thin layer of clean, dry stone chips is applied over the surface of the seal coat and thoroughly rolled.

105. Asphalt Blocks.—A bituminous concrete having the essential features of the Topeka grading has been used for many years in the form of asphalt blocks. These blocks consist of a hard mineral aggregate, a filler, and a suitable asphalt cement. It has been found that freshly crushed trap rock or copper conglomerate makes the most satisfactory and durable mineral aggregate. The heated trap-rock, filler, usually limestone dust, and asphalt cement are mixed in a pug-mill mixer. The mixed material is then fed into a hydraulic press, where it is subjected to a pressure per block of between 225 and 240 tons. The blocks, after being cooled under water, are ready for use. Many blocks are manufactured in standard sizes of 12 inches long, 5 inches wide, and 2, $2\frac{1}{2}$, or 3 inches thick. The blocks should be laid in a

cement-mortar cushion, $\frac{1}{2}$ inch in thickness, covering a cement-concrete foundation 5 to 6 inches in thickness, and rolled with a 9- to 12-ton tandem roller. The pavement is finished by brooming sand into the joints as thoroughly as possible.

106. Maintenance.—Because of ordinary wear under traffic, the seal coat of a bituminous-concrete pavement requires repairing independent of repairs to the bituminous concrete of the wearing course. Bare spots will be found early in the life of some pavements, due to wear and to lack of uniformity in the distribution of the bituminous cement for the seal coat during the construction of the pavement. Such areas may be satisfactorily repaired by thoroughly cleaning the exposed surface, and, when dry, applying hot bituminous cement with a broom or brush, using from $\frac{1}{8}$ to $\frac{1}{2}$ gallon per square yard. For a close mosaic surface, the bituminous cement should be covered with a thin dressing of Portland cement, while, if the surface is porous, stone chips should be used.

The most efficient method of repairing a bituminous-concrete wearing course is to use the same kind of mineral aggregate and the same kind of bituminous cement that was employed in the construction of the pavement. Usually, fulfilment of the above requirements necessitates the heating of the mineral aggregate as well as the bituminous cement. By this method of repairing, maximum homogeneity of the wearing course is obtained and sufficient stability is secured to prevent the newly-laid bituminous concrete from being displaced by traffic. For light repairs to Class *A* pavements, satisfactory results have been obtained by using proper mixtures of unheated road metal and either an unheated cut-back asphalt or a tar cement.

MECHANICAL APPLIANCES

107. Mixing Plants.—To meet the demand for a mixing plant by which various types of mineral aggregates can be economically heated and mixed with bituminous cement, several machines have been designed in the United States. The

requirements of engineers vary to a considerable extent, due to the different kinds of aggregates and bituminous materials employed. Mixing plants may be divided into three classes: (*a*) Cement-concrete mixers; (*b*) cement-concrete mixers with heating attachments; and (*c*) plants consisting of a dryer, storage bins, and mixer.

108. Cement-Concrete Mixers.—Unheated broken stone has been mixed with tars or heavy asphaltic oils in the ordinary type of concrete mixer. With this type of plant, asphalt cements of low penetration at normal temperature cannot be mixed with unheated aggregates, as it is generally impracticable to coat the unheated broken stone with the previously heated asphalt cement. This class of mixers should not be used for the construction of bituminous-concrete pavements.

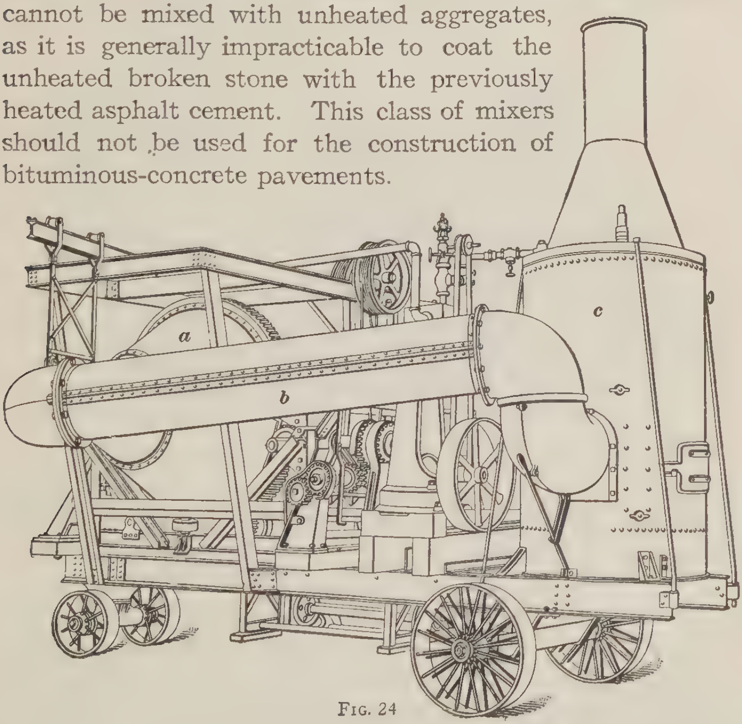


FIG. 24

109. Cement-Concrete Mixers With Heating Attachments.—There are in current use several different types of mixing plants having heating attachments. In the type shown in Fig. 24, the heat, in the form of hot air, is passed into the mixer *a* by means of a large iron pipe *b*, which runs

from the firebox of the boiler *c* to the outlet end of the mixer. Another type of mixer consists of a cylindrical mixer mounted on a four-wheeled truck. Heat is obtained from a hot-air jacket, entirely surrounding the cylinder except on the ends, by means of a kerosene torch inserted within a drum. In a third type, hot air obtained by the combustion of oil in air is led from the combustion chamber into the mixing box. After

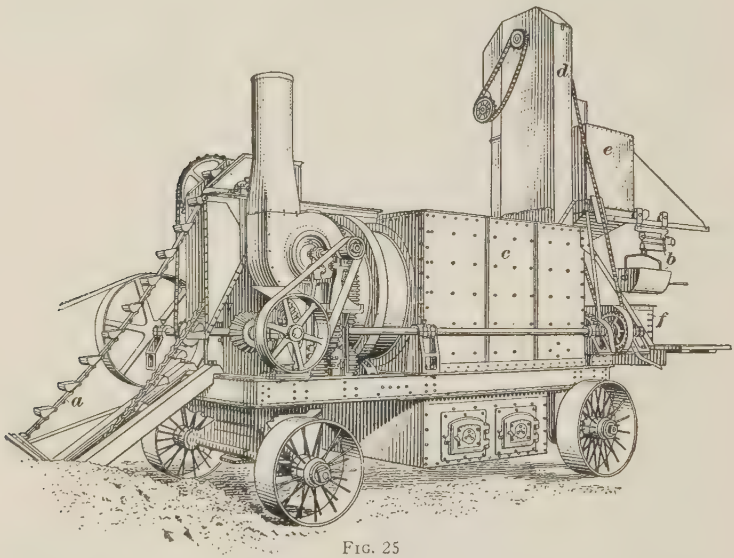


Fig. 25

the mineral aggregate is heated the bituminous cement is added. In another method of utilizing concrete mixers a rotary dryer for drying the aggregate is used as a part of the plant.

110. Dryers, Storage Bins, and Mixers.—In several types of plants, the aggregate is heated in rotary dryers from which the dried material is transported by elevators to storage bins. As required, the aggregate falls by gravity into the mixer. The heat for the dryer and the mixer is obtained by direct heat from fireboxes or by oil-burning apparatus. In the complete plant, Fig. 25, the aggregate is drawn by means of the elevator *a* to the dryer *c* and then raised by the elevator *d* to the bins *e*. The aggregate is weighed by scales, which

are directly beneath the bins *e*, while the bituminous cement is weighed by the scale and bucket *b*. The aggregate and the bituminous cement are mixed in the mixer *f*, from which the bituminous aggregate drops through doors into wagons or trucks.

111. Bitulithic Plant and Its Operation.—Bitulithic is mixed in a semiportable plant as follows: The raw materials, namely, crushed stone, screenings, and sand, are fed from the storage piles at the rear of the plant into the cold-stone elevators, are heated in the driers, then elevated to the rotary screen, which is enclosed in a screen house to prevent the dust from scattering over the neighborhood. The screen consists of the several sections which are required to separate the mineral aggregate into the various sizes. The hot stone passing each of these screen sections drops into its compartment in a sectional bin and is thus kept separate from other sizes. The box man weighs out the amount of each size required into a weigh box supported on platform scales that have a multiple beam which enables him to weigh each size separately and accurately. It is impossible to formulate a standard screen test or rule as to just what proportion of each size particle of mineral aggregate is required to produce the maximum density or minimum of voids, because the stone from different quarries crushes into different shapes. By following the best practice under the Warren patents, the resulting combination of varying sizes of mineral aggregate will contain approximately 12 per cent. of voids to be filled with bitumen. While the weighing is taking place, the mixer man has filled the bitumen bucket with the required weight of Bitulithic cement by dipping from the melting tanks, the weight of bitumen being accurately measured by scales on the bucket carrier. The bitumen and mineral aggregate are then emptied into the mixer and thoroughly mixed until all particles are completely coated and the mass has been transformed into a uniform bituminous concrete, then the slide under the mixer is opened and the batch is dropped into the wagon waiting under the platform.

112. Warrenite Plant and Its Operation.*—While the mixture produced by the Warrenite plant is much like Bitulithic, the methods by which it is obtained are radically different from those in use with the Bitulithic plants. The crushed stone, screenings, and sand are placed in separate piles, and the required proportion of each size, as previously determined by laboratory test, is measured into the drying section of the plant and there remains until dried. One full batch of mineral aggregate measured in this manner is fed into the elevator and raised to the hopper. After the entire batch is in the hopper, the gate in the chute allows it to descend into the heater drum, which is heated by an oil flame through the combustion chamber. While the batch is being heated, it is slowly forced forward toward the mixing chamber by spirals inside the drum. When it is hot enough, a gate or chute suspended between the heating and the mixing chambers of the drum is tilted and conveys the entire batch into the mixing chamber, where it is thoroughly mixed with Warrenite cement poured in through a funnel above the platform. The bitumen is weighed accurately in a bucket on spring scales, the same as in a Bitulithic plant.

When the batch is mixed, it is delivered into the wagon by another tilting chute at the forward end of the mixing chamber. While one batch is going through this process, other batches have been successively started, so that at any one moment there is one batch in the mixer, one in the heater, one in the hopper, and one being measured in the wheelbarrows; yet on account of the design of the plant each batch is kept entirely separate and distinct from every other, and for that reason it is possible to control the mixture and keep the proportions of the various sized particles of the mineral aggregate constant and uniform.

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*By G. H. Perkins in Journal, Boston Society of Civil Engineers, March, 1914, page 119.

HIGHWAYS

(PART 4)

SHEET-ASPHALT AND CEMENT-CONCRETE PAVEMENTS

SHEET-ASPHALT PAVEMENTS

COMPOSITION AND PROPERTIES

1. Principal Pavement Systems Compared.—The asphalt pavements of Europe differ somewhat in their construction from those of America, owing to the difference in the character of the materials used. The European asphalt pavements are composed of limestone naturally impregnated with bitumen, while American asphalt pavements are formed from artificial mixtures of bitumen, sand, and pulverized limestone. The pavements composed of natural bituminous limestone become hard, smooth, and slippery under traffic, and are not so satisfactory in frosty latitudes as those constructed from artificial mixtures; the sand contained in the latter material lessens its slipperiness.

2. Composition and Properties of Sheet-Asphalt Pavement.—Sheet-asphalt pavement, when properly constructed on a cement-concrete foundation, is durable under heavy traffic such as is characteristic of the streets of shopping

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districts in large cities. Such pavement is very low in tractive resistance, easy to clean, and does not produce dust from abrasion of the wearing course. It usually is slippery on grades of over 3 to 5 per cent. When in good condition, very little noise results from the passage of the wheels of vehicles, but horses' hoofs striking the pavement give off a sharp metallic sound.

3. A part of a roadway with sheet-asphalt pavement is shown in perspective in Fig. 1. In this view *a* is the sheet-asphalt wearing course; *b*, the binder course; *c*, the concrete

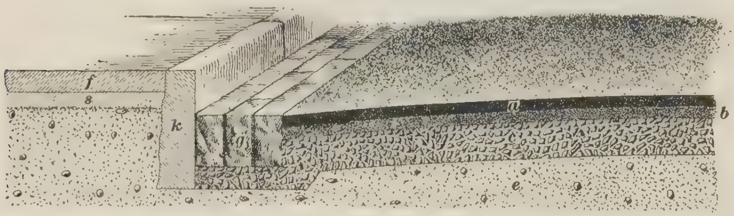

FIG. 1

base, and *e*, the earth subgrade. The gutter, in this case, is paved with granite blocks *g*; *f* is the flagstone of the sidewalk; *k*, the curbstone; and *s*, the sand bed on which the flagstones are resting.

4. Foundations.—It is essential that all sheet-asphalt pavements should be sustained by a solid unyielding foundation, as the sheet asphalt and rock asphalt are suitable for a wearing surface only. Two kinds of materials are employed for the foundation; namely, hydraulic-cement concrete and bituminous concrete. Each material has its advantages, but the hydraulic-cement concrete is generally preferred. The cement-concrete foundations for sheet-asphalt pavements are usually from 4 to 8 inches in depth, according to the character of the traffic and the nature of the subsoil.

CONSTRUCTION AND MAINTENANCE OF SHEET-ASPHALT PAVEMENTS

5. Asphalt Cement.—The bituminous material that is used in the construction of sheet-asphalt pavements is known as *asphalt cement.* In the trade, the abbreviation *A. C.* is in common use. The asphalt cements used in the United States and Canada are described by the following definition, which is taken from the Proceedings of the American Society of Civil Engineers, Dec., 1914, page 3011:

Asphalt Cement: A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements, and having a penetration of between 5 and 250.

Many specifications for sheet-asphalt pavements have included clauses covering the chemical and physical properties of refined asphalt (abbreviated *R. A.*), flux, and asphalt cement. Furthermore, some specifications have covered the method by which the refined asphalt and flux should be combined in order to form the asphalt cement. There is a marked tendency among engineers and chemists to place emphasis upon the specification for the asphalt cement and omit speci-

TABLE I

GRADING OF SAND FOR SHEET-ASPHALT PAVEMENT

Minimum Sizes of Sieve Passed Through	Maximum Sizes of Sieve on Which Retained	Amount Per Cent.	
200-mesh		0 to 5	25 to 35
100-mesh	200-mesh	14 to 25	
80-mesh	100-mesh	6 to 21	
50-mesh	80-mesh	15 to 30	40 to 50
40-mesh	50-mesh	10 to 25	
30-mesh	40-mesh	8 to 20	20 to 30
20-mesh	30-mesh	5 to 15	
10-mesh	20-mesh	2 to 15	

fications for the refined asphalt and the flux. This practice is based on the belief that comprehensive and suitable specifications covering the physical and chemical properties of the asphalt cement are sufficient, since the asphalt cement is the bituminous material that is used in the pavement.

6. Sand and Filler.—The following description of sand and filler may be considered typical for the materials of a wearing course to be subjected to medium traffic. The sand should be clean, hard-grained, and moderately sharp. The product used should show the mesh composition given in Table I. The mineral filler should be thoroughly dry, fine, limestone dust, dolomite dust, or Portland cement.

7. Binder Course.—In order to effect a more complete bond, an intermediate layer of bituminous concrete is commonly placed between the concrete foundation and the sheet-asphalt wearing course; this is known as the binder course. It may be composed of bituminous concrete of Class A, B, or C, the concrete of Class A being designated an *open binder*, and that of Classes B and C as *closed binders*. The stones, which are heated to a temperature of from 200° to 325° F., should be mixed with the hot paving cement. This mixture should be spread, while hot, on the base course to such a depth as will consolidate to a thickness of from 1 to 1½ inches; it should then be rolled, before it loses its plastic condition, with a 10 to 12-ton tandem roller until thoroughly compacted.

8. Wearing Course.—The wearing course, which is the top course exposed to traffic, consists of the aggregate, sand and filler, and the asphalt cement, and is usually 1½ to 2 inches in depth after rolling. The amount of bitumen used varies from 9 to 13 per cent. It is brought onto the street at a temperature of 280° to 325° F. (depending upon the type of asphalt cement used), dumped, and spread on the binder surface, and then tamped around all manholes, gutters, and curbs, and rolled with a tandem roller weighing 5 to 10 tons. Continuous rolling is very essential, as a constant kneading action is necessary to secure a well-compacted surface. Special care

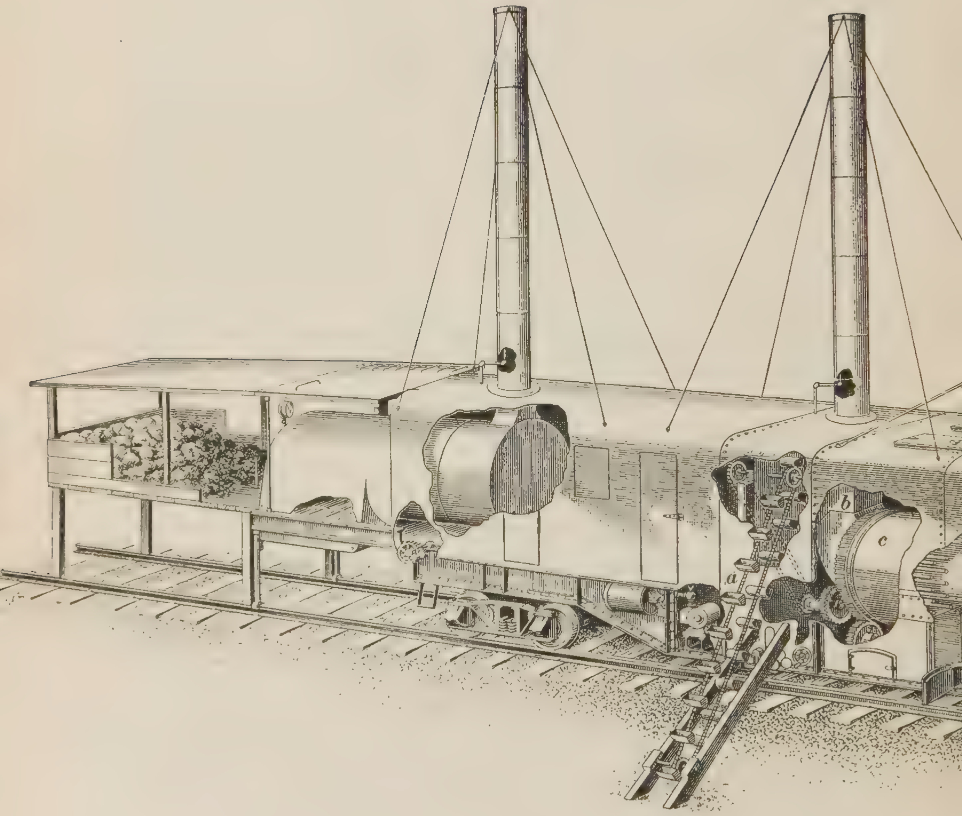

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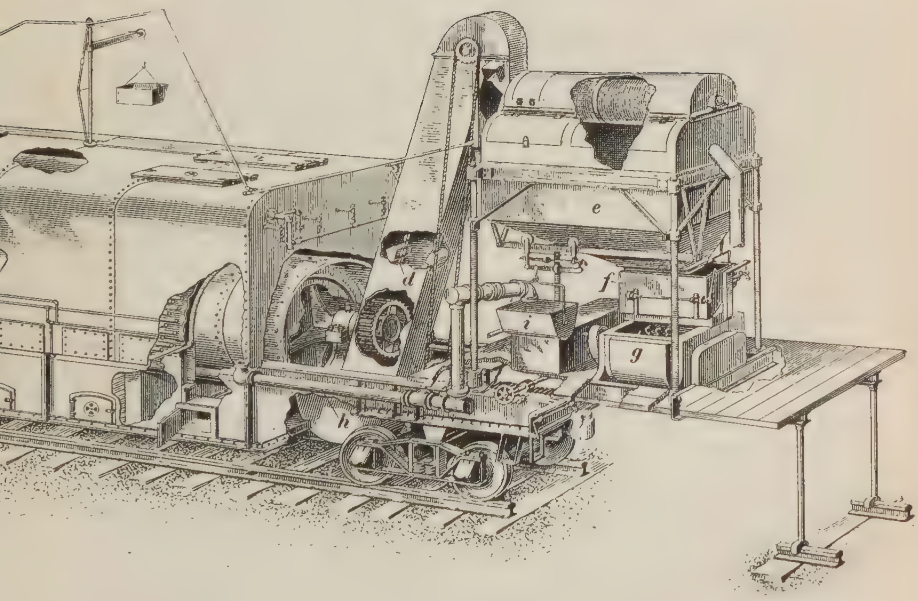
FIG.


d
e
f
g
h
i

must be taken along street-car rails to secure thorough compaction. Usually one to three courses of stone block or brick are laid next to the rail.

9. In preparing the mixture for the sheet-asphalt wearing course the sand and asphalt cement are first heated in separate heaters and then mixed while hot. In order to prevent burning, it is advisable to keep the asphalt cement agitated while it is being heated, especially when the heater or melting tank is heated by direct fire. Agitation may be accomplished by blowing air or superheated steam through the asphalt cement, or by mechanical means. When the asphalt cement contains a considerable amount of foreign material, the agitation prevents the impurities from settling to the bottom of the melting tank and helps to obtain a uniform composition.

10. The proportions of the ingredients of the mixture for the sheet-asphalt wearing course should be determined by weighing. The ingredients are mixed in a small mixer which has a capacity of from 10 to 15 cubic feet. The mixer usually consists of a semicylindrical trough, within which are a series of paddle wheels which revolve on a horizontal axle. These paddles agitate the ingredients and produce the mix.

11. Asphalt Plant.—A complete portable plant for heating, weighing, and mixing the ingredients for sheet-asphalt mixtures is illustrated in Fig. 2. The plant shown in the illustration is known as the Merriman asphalt plant. The cold sand is placed on both sides of the plant at the base of the cold-sand elevators *a* and is raised by the elevators to the hoppers *b*, from which it runs into the revolving drying drum *c* and is carried through it by means of spiral flights to the discharge end. While passing through the drum, the sand is thoroughly dried and heated to the proper temperature. From the discharge end, the sand drops into the hot-sand elevator *d*, which carries it up to a revolving screen where it is screened and discharged into the hot-sand storage bin *e*. From the bin the sand is run into the weigh box *f* from which it is dumped into the mixer *g*, where it is mixed with the proper

amount of melted asphalt cement for about $1\frac{1}{2}$ minutes. The material is then dumped through the bottom of the mixer into trucks and rushed to the street that is to be paved.

The asphalt cement is melted in kettles, which are set over the drum. Agitation in the kettles, while the asphalt cement is being melted, is maintained by blowing air or steam through the material. The air pressure is also utilized to force the molten asphalt cement through the asphalt delivery pipes *h* into the asphalt bucket *i*, where it is weighed and dumped into the mixer.

12. Gutter Surfaces.—Sheet-asphalt paving material is not entirely impervious to water, and when it is in continual contact with water it tends to rot or disintegrate. With some kinds of asphalt, the disintegration is much more rapid than with others, while with asphalt obtained from certain sources, the paving material is said not to be affected by water.

As pure asphalt is quite impervious to water, the gutter surfaces are sometimes coated with it in order to render them impervious and protect the underlying material. It is customary to coat a width of 12 to 24 inches adjacent to each curb. The asphalt should be placed on the surface in a hot state, and smoothed with hot smoothing irons, in order to impregnate the surface of the underlying asphaltic material with an excess of asphalt.

In some cases, the gutters are formed of granite blocks, brick, or other suitable material not of an asphaltic nature.

13. Maintenance.—Repairs to sheet-asphalt pavements, necessitated by failures of the foundation, binder course, or lower part of the wearing course, are made by cutting out the defective parts and replacing them by freshly prepared materials. If large areas of the upper surface of the wearing course are to be repaired, it is economical to use the surface-heater method. This method consists in burning the surface with special machines for a depth of not less than $\frac{1}{4}$ inch. After all burnt and loose material has been removed, new paving mixture, as required, is added and thoroughly compacted.

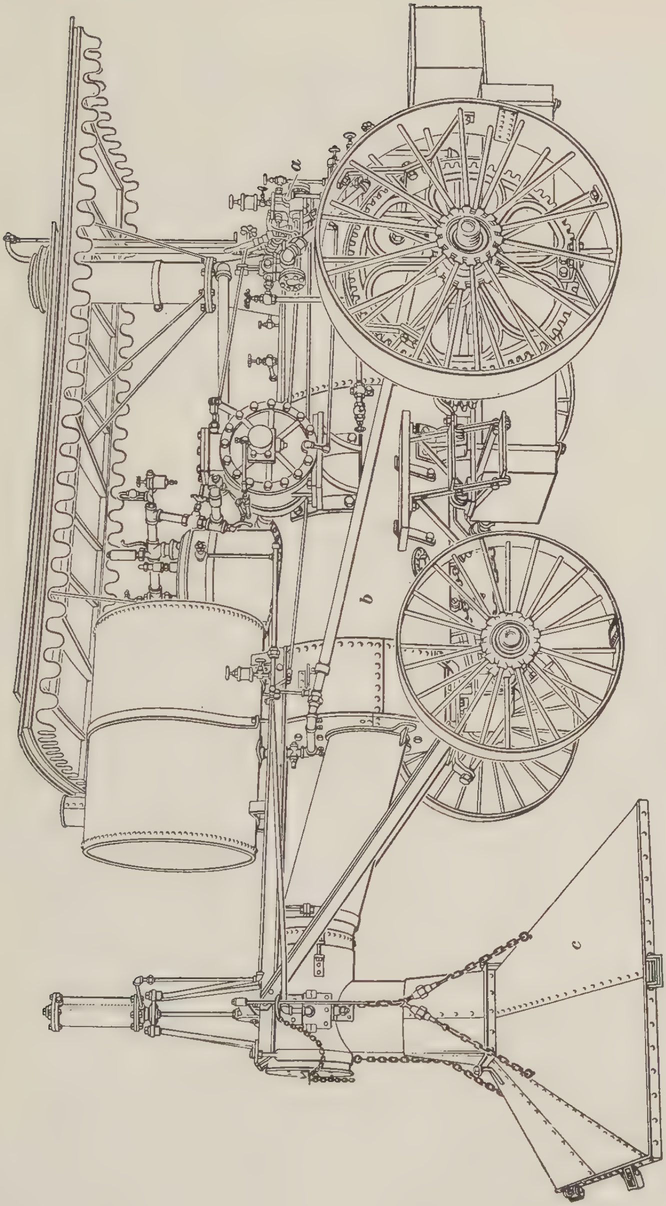


FIG. 3

In Fig. 3 is illustrated the Lutz surface heater, a machine often used in repairing sheet-asphalt pavements. It consists of a traction engine *a*, a heating chamber *b*, and a hood *c*. When the machine is in operation, a large quantity of air, heated to the proper temperature in the heating chamber, is blown with great force through the hood upon the sheet-asphalt pavement. This softens the pavement sufficiently to allow the removal of all disintegrated and worn material with hoe and rake. While the pavement is still hot, new material is added and the pavement is brought to the proper grade and contour, the new material being tamped, smoothed, and rolled. A good weld between the new and old material is thus obtained.

ROCK-ASPHALT PAVEMENTS

14. Composition.—Natural, or rock, asphalt, as commonly used for paving purposes in Europe, consists of limestone naturally impregnated with bitumen in such proportion that it may be softened by heat, and again consolidated in the required form when cooled under pressure. This material is also known as bituminous rock.

Sandstone rock similarly impregnated with bitumen is found in many places in the United States, and has been used to some extent for paving purposes. The use of rock asphalts for pavements, however, has scarcely passed beyond an experimental stage in this country. It is claimed that rock asphalts resist disintegration by moisture, and that they stand high temperatures and cold, damp atmospheres equally well. A binder course is not employed; but the rock asphalt, properly prepared, is laid directly on the concrete foundation, which should preferably be of hydraulic-cement concrete.

15. Preparing Rock Asphalt.—Rock asphalt is used to form the wearing course of the pavement. In order to be suitable for this purpose, the natural rock should contain from about 8 to 13 per cent. of bitumen. If it contains more than 13 per cent., it is likely to become soft in warm weather; and if it contains less than 8 per cent., it will not consolidate

thoroughly nor have sufficient bond; a range not greater than from 9 to 12 per cent. is preferable. The bitumen should be evenly distributed through the rock, which should be of nearly uniform texture. In order to obtain the proper percentage of bitumen, it is sometimes necessary to mix together rocks obtained from different localities.

The rock is first crushed to fragments of about the size of eggs, and then ground to a fine powder. This powder is heated to about 300° F. to soften it to the required consistency.

16. Laying Rock Asphalt.—The hot material is delivered on the roadway and by means of hot iron rakes is spread over the concrete foundation to such a depth that it will compress to the required thickness. The thickness of the wearing surface after compression should not be less than 2 inches; a compressed thickness of 2 inches requires a depth of about 3 inches for the uncompressed material. Proper precautions should be taken to prevent too much cooling of the asphalt while it is being transported to the pavement. The asphalt should be laid in dry weather and on a perfectly clean foundation from which all loose or foreign substances have been removed.

The material, when spread on the foundation, should be vigorously rammed with hot cast-iron rammers of from 6 to 8 inches in diameter, a sufficient number of laborers being used to ram the material to a compact condition while still hot. Soon afterwards, the surface should be rolled with a light roller heated by an internal furnace. A small quantity of hydraulic cement should be swept lightly over the surface during the process of rolling, which should be continued until the asphalt is cooled. The final compression of the pavement is usually left to be effected by the wheels of the traffic.

Owing to the limited use of rock-asphalt pavements in the United States, the specifications and methods of construction are not well standardized. The method of laying the rock asphalt as here described corresponds more closely to the European than the American practice, although it may be considered as fairly representative of the latter.

CEMENT-CONCRETE PAVEMENTS

COMPOSITION AND PROPERTIES

17. Characteristics.—A cement-concrete pavement has a wearing course composed of broken stone, broken slag, or gravel, and sand or other fine aggregate cemented together with Portland cement. It furnishes a smooth surface when first constructed, which is easy to clean and is not productive of much dust, but is somewhat noisy. If properly constructed, it is suitable for roadways of trunk highways subjected to commercial traffic.

The utilization of cement concrete in foundations is of long standing in the United States. Its record as an efficient foundation, especially when laid on a well-drained roadbed, is well known to engineers. The cement-concrete pavement is as yet in its infancy as compared with roadways of broken stone, stone block, and some others. In considering its use on the highways, therefore, its dual capacity should be kept in mind. It may be economical to use cement-concrete pavements constructed at such a grade level that after their period of life as pavements has expired they may serve efficiently as foundations for new wearing courses.

18. Natural Foundations.—Cement-concrete pavements should be laid only on a well-compacted and well-drained subgrade. If the subgrade is of clay, it should be replaced with clinker, broken stone, cinders, gravel, or some other suitable material. The surface should be thoroughly rolled with a medium-weight roller. Before the concrete is deposited, the subgrade should be sprinkled with water; otherwise the subgrade will absorb water from the concrete, thus preventing a uniform set and decreasing its strength.

19. Materials.—The materials used for the aggregate of a cement-concrete pavement are generally sand and either broken stone or gravel. The broken stone employed should be obtained by crushing hard, tough rock. Preferably, the stone

should be composed of graded sizes and be free from dust or dirt. What has been said relative to broken stone applies as well to gravel, since a screened gravel with the fine material eliminated allows a more accurate determination of the correct proportions. The sand used should be clean and coarse, free from loam, clay, and any vegetable or organic matter. The cement should be a first-class Portland cement. Care should be taken to use clean water, since water that contains any alkalies or acids will be detrimental to the concrete. The proportions commonly used in the construction of concrete foundations are not rich enough in either cement or mortar to make a satisfactory concrete that is to be subjected to the abrasive and impact forces of traffic. The proportions of cement, sand, and gravel, as used for first-class cement-concrete pavements, vary from 1 : $1\frac{1}{2}$: 3 to 1 : 2 : 4.

CONSTRUCTION AND MAINTENANCE

20. Number of Courses.—There are several methods of constructing cement-concrete pavements, but the most satisfactory, and the method usually employed, is to construct the pavement in one course by depositing mixed cement concrete on the subgrade. The concrete is sometimes deposited in two layers. It is evident that in constructing a two-course pavement there will be a plane of weakness between the two courses. Although it is possible in the two-course method to construct the top with a richer mix, this does not offset the advantages derived from having the entire depth of concrete deposited at one time.

21. Mixing Cement Concrete.—The essential features of the methods for mixing cement concrete as recommended by the Committee of the National Conference on Concrete Road Building are as follows: The concrete mixer should be of the batch type provided with an automatic water tank, traction drive, and power loader. Mixers having a boom and bottom-dump bucket of sufficient size to convey one complete batch for placing the mixed concrete are preferred. A mixer

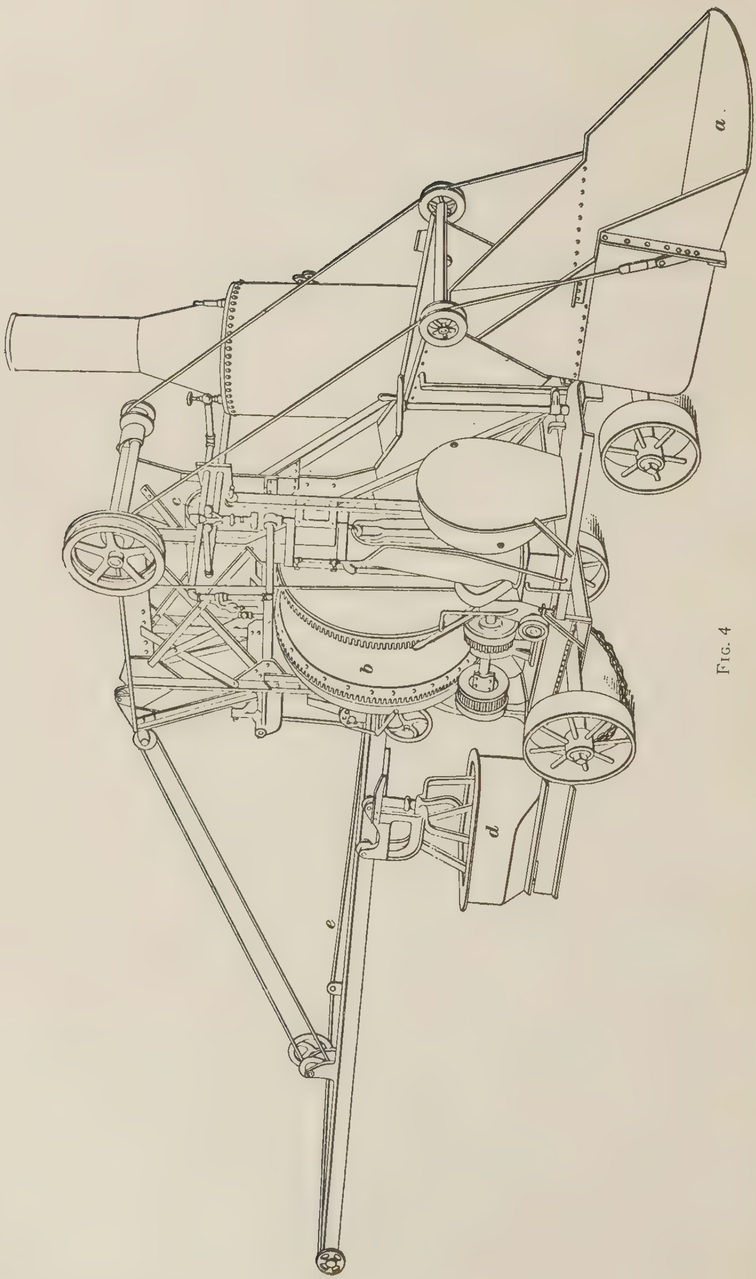


Fig. 4

of this construction is shown in Fig. 4. Where necessary to keep from cutting into the subgrade and to facilitate moving, the wheels of the mixer should be run on suitable planking.

The mixer should be provided with a suitable automatic water tank which can be quickly filled and emptied, so that, when once determined, the required amount of water can be added to each batch of concrete. The power loader, or skip, *a*, Fig. 4, should be of sufficient size to hold all the materials required for the batch. In charging the skip, a part or all of the coarse aggregate should be placed first, and the cement, fine aggregate, and remaining coarse aggregate, if any, on top of this. All the cement should be in the skip before the last of the aggregate is added. The filling of the skip is accomplished in practice in two ways: by the use of wheelbarrows or by shoveling direct from the supply piles into the skip. This latter practice, however, should be discouraged, for it is not conducive to accuracy, and it promotes carelessness. Besides, the entire loading gang loses time waiting while the skip is raised and lowered. It is recommended that all the materials in any one batch, including the water, should remain in the drum of the mixer at least 45 seconds before any of the concrete is discharged.

22. In the mixer, Fig. 4, the material required for one batch is placed in the skip *a*, which is then raised so as to dump its contents into the mixing drum *b*. At *c* is a water-measuring tank that supplies the correct amount of water for each batch. The machine is provided with a traction drive, which allows it to be brought into a position where the material can be handled in the most efficient manner. The mixed material is delivered by the mixer to the bucket *d*, which travels along the adjustable boom *e* to the point of delivery. The boom can swing horizontally through an arc of 180°; thus, with a boom 20 feet long the bucket can be dumped at any point of a roadway 40 feet wide. The action of the bucket is entirely automatic; it will travel along the boom to a predetermined point, open its gates and return to the mixer, close its gates and disengage itself from the traveling cable.

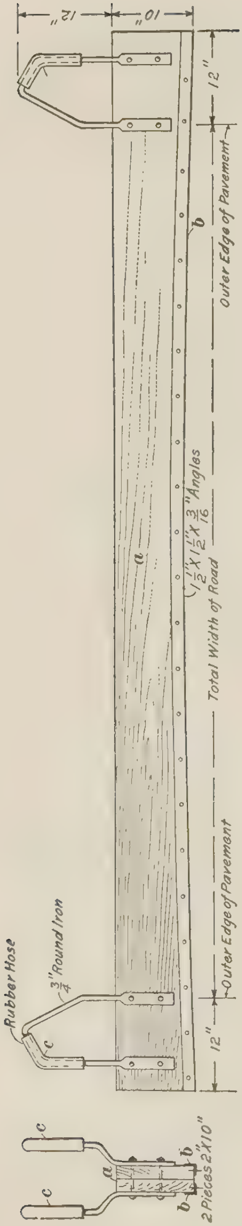


FIG. 5

23. Strikeboard Method of Finishing.—More attention should be paid to obtaining a smooth surface in constructing cement-concrete pavements than is usually the case with concrete foundations. A heavy strikeboard is used to obtain a uniform thickness and to tamp the concrete. The strikeboard is drawn over the roughly shaped concrete until an even surface is secured. An efficient form of strikeboard is shown in side view and cross-section in Fig. 5. The lower edges of the strikeboard *a* are beveled to fit the crown of the street and are covered with two $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{3}{16}''$ angle irons *b*, and each end of the board is provided with two rubber-covered handles *c*.

24. The concrete may be finished by the roller-and-belt method, recommended by a Committee of the American Concrete Institute. The following manipulation is used: As soon as possible after the concrete has been struck off it should be rolled with an approved metal roller having a smooth, even surface, approximately 6 feet in length, not less than 8 inches nor more than 12 inches in diameter, and weighing not more than 100 pounds. Fig. 6 shows an approved roller *a* made of $\frac{1}{8}$-inch galvanized-iron plate and provided with a wooden handle *b*, 20 feet long. On pavements less than 20 feet in width, the roller may be operated with a handle that is at least 2 feet

longer than the width of the pavement, and all rolling should be done from one side of the slab. On pavements 20 feet and more in width, the roller is provided with two bails, to which ropes are attached, and the roller is pulled across the pavement. The roller is operated at such an angle with the center line of the pavement that it will advance along the pavement about 2 feet for each time across. The roller should be passed from one edge of the pavement to the other, care being taken not to run the roller over the side forms so that earth or other foreign material will adhere to it. After the roller has covered a given area in the manner described, the same area is similarly covered by the roller not less than three times at intervals of 15 to 40 minutes, and as many times additional as may be necessary to remove excess water.

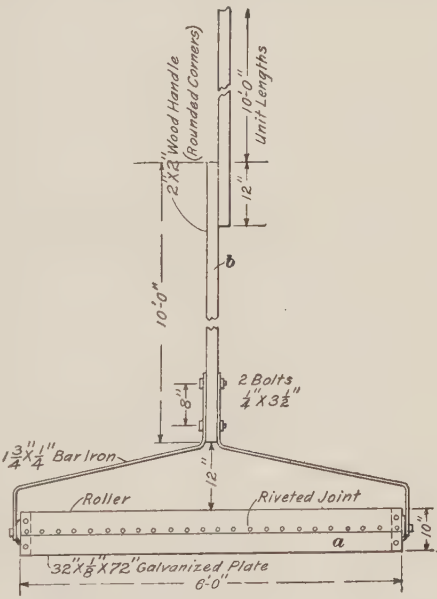


FIG. 6

After the rolling has been completed, the pavement is finished by two applications of a belt made of canvas or rubber belting, not less than 6 inches wide and not less than 2 feet longer than the width of the pavement. The belt is applied with a combined crosswise and longitudinal motion. For the first application vigorous strokes at least 12 inches long should be used, and the longitudinal movement of the belt should be very slight. The second application of the belt should be immediately after the water glaze disappears, and the stroke of the belt should be not more than 4 inches but the longitudinal movement should be much greater than for the first application.

25. It is important to protect the surface from too rapid drying out while the concrete is curing, as otherwise shrinkage cracks are liable to occur. This is accomplished sometimes by covering the pavement, as soon as it has taken its initial set, with a canvas which is kept moist for a few hours. The canvas is then removed and the surface is covered with a layer of sand or earth, which is kept thoroughly moist for a period of 2 weeks. Another method of curing is to keep the surface of the concrete covered with a pond of water, about 2 inches deep, for about 10 days.

26. Expansion Joints.—Transverse joints should always be provided. There will be more or less contraction and expansion of the concrete due to changes of temperature, variation in the moisture content of concrete, and variation in the condition and character of the subgrade. If expansion joints are not present, when the concrete contracts, the tensile strength of the concrete will be exceeded and the pavement will crack; when it expands it will tend to crush, spall, or bulge. It is obvious that the joints should be filled with a material that will allow some movement between the joints as the pavement expands and contracts. The width of the transverse joints depends upon the distance between them, and is usually made from $\frac{1}{4}$ to $\frac{1}{2}$ inch. It is considered better practice to construct narrow joints at short distances apart rather than wide ones far apart. Transverse joints are placed from 15 to 50 feet apart, 30 feet being an average distance. If curbs are used, longitudinal joints should be constructed adjacent thereto. The width of the longitudinal joints will depend somewhat upon the width of the pavement. They are usually made $\frac{1}{4}$ to 1 inch wide.

27. Expansion joints usually consist of some type of bituminous filler with or without a fiber matrix. Patented expansion joints have also been used. As an example of a patented expansion joint may be mentioned that employed on a concrete pavement constructed in Michigan. To protect the edges of the joints, two soft-steel plates $\frac{1}{2}$ inch thick and 3 inches wide were built into the road. To these was clamped a divid-

ing board shaped to conform to the crown of the road. The plates were securely tied to the concrete base and wearing surface. Between the plates were two thicknesses of 3-ply asphalted cement felt about $\frac{1}{4}$ inch thick and extending the entire depth of the concrete.

28. Reinforced Cement Concrete.—Reinforced-concrete pavements are usually constructed by the two-course method. The reinforcement may consist of woven wire, shown in Fig. 7, or of expanded metal, although a meshwork of small round bars is sometimes used. The reinforcement is placed between the base and the wearing surface. In many instances where pavements have been constructed in this manner, both longitudinal expansion joints at the curbs, and transverse expansion joints at intervals across the pavement, have been built.

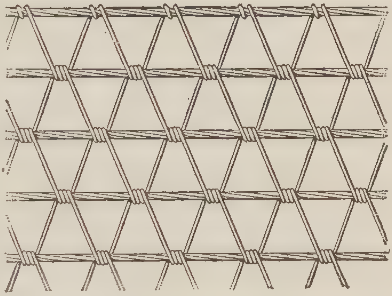


Fig. 7

29. Maintenance. Defective spots are liable to occur, due to a poor mixture or a segregation of the ingredients when the concrete is placed. When the weak concrete in such spots starts to wear away, the worn area grows in extent very rapidly, the abrasive action of the traffic grinding out the good concrete. Such places should, therefore, be immediately repaired, which is best accomplished by cutting them out for a depth of at least 3 inches and refilling with either cement or bituminous concrete, depending primarily upon the traffic conditions. Places where cracks have formed should also receive very close attention, since the edges of the cracks and the surface adjacent to them soon wear away. Filling the cracks with a bituminous filler will serve to protect the edges and prevent water from seeping down through the pavement to the subgrade. Care should also be taken to have the expansion joints always filled flush with a bituminous filler.

BRICK AND STONE-BLOCK PAVEMENTS

BRICK PAVEMENTS

COMPOSITION AND PROPERTIES

30. Characteristics.—Although brick was one of the first of the materials used for paving, it has not been extensively used for this purpose until recent years. It is not equal to granite as a paving material for roadways sustaining an exceedingly heavy traffic. A brick pavement, however, when constructed in a proper manner and of suitable materials, forms a smooth, durable surface well adapted to moderate traffic. If properly built with a bituminous or cement-grout filler, the surface wears smooth, offers slight resistance to traction, is easy to clean, produces no dust, and furnishes a fair foothold for horses. If proper allowances are not made for expansion and contraction when cement-grout filler is used, the pavement is liable to arch itself above the sand cushion and become noisy, which is a decided objection. A bituminous filler prevents the occurrence of such a condition, but unless the proper kind of bituminous filler is used, the edges of the bricks wear and round off under the action of traffic. If a grout filler is used on steep grades, the pavement may become very slippery. A bituminous filler will be found to be of material advantage in such cases.

31. Foundations.—Many kinds of foundations, such as sand, gravel, sand and boards, broken stone, etc., have been employed for brick pavements. They have all proved more or less defective, and experience shows that the foundation should in all cases be composed of hydraulic-cement concrete. In localities where broken stone and gravel are difficult to obtain, the aggregate of the concrete may consist of broken brick.

CONSTRUCTION AND MAINTENANCE

32. Brick Pavement With Sand Cushion.—Brick pavement is often laid on a sand cushion supported on a cement-concrete foundation. Sandy material that will pass through a ¼-inch screen is spread on the foundation in such amount that it will have a thickness of ¾ to 1½ inches when the cushion is completed. After the sand is carefully leveled off by means of a templet so that the surface of the sand is parallel to the finished surface of the pavement, it is then rolled with a light hand roller. A well-compacted, even sand cushion is one of the most important details in the construction of brick pavements.

33. Laying the Bricks.—The bricks should be set edgewise on the sand cushion, with their sides and ends in close contact. They should extend in parallel courses across the street, with their lengths perpendicular to the axis of the street, and should be so laid that the bricks of adjoining courses will break joints by a lap of not less than 3 inches. At street intersections, the courses should extend diagonally. If lug bricks are used, care should always be taken to place the lug sides on the same side of the course. On the completion of every fourth course, the bricks should be driven together so as to secure tight joints and straight courses. The end joints are made tight by the use of a bar between the end of each row and the curb. To avoid disturbing the sand cushion, the laborers should stand on the bricks as they are laid.

34. Rolling.—When the pavement has been prepared as described, it is ready for rolling. A tandem roller weighing not less than 3 nor more than 5 tons is generally used. Rolling is commenced near the curb, the roller traveling parallel to the curb back and forth at a slow speed and gradually working across the surface toward the center. When the center is reached, the roller starts at the opposite curb and rolling again progresses to the center as before. Rolling is continued as described until the bricks are firmly fixed. Cross rolling is usually required wherein the roller travels at an angle of

45 degrees from curb to curb and then in the opposite 45-degree direction. Any broken or unsatisfactory bricks found during the work of rolling are replaced. Upon completion of the rolling, the surface may be tested with a 10-foot straightedge. Some specifications require the removal and relaying of any parts that show a depression exceeding $\frac{1}{4}$ inch when tested by this method.

35. Expansion-Contraction Joints.—To provide for expansion and contraction of the pavement, it is common practice to insert boards between the curb and the pavement that will provide a space from 1 to $1\frac{1}{2}$ inches wide. After the pavement is otherwise completed, the board or boards are removed and this space is thoroughly cleaned out and filled with a bituminous filler. Longitudinal expansion is sometimes provided for in a cement-grout-filled pavement by filling with a bituminous filler the joints of four to six adjacent rows of bricks about every 25 to 50 feet along the street. If the pavements are constructed in the hottest months of the year, the bricks, being in an expanded condition when laid, will not expand so much after the pavement is constructed as when they are laid in a cold season. When a brick pavement cannot expand in its normal plane, the brick wearing course arches up over the sand cushion. In some cases the expansion is sufficient to force the pavement up several feet. Frequently cracks are formed in the surface due to contraction.

36. Joint Fillers.—After the pavement has been rolled, the joints should be filled with some suitable material. Sand, cement grout, coal-tar pitch, and asphalt have been used as joint fillers.

Sand was used for a joint filler in the earliest type of brick pavements. In many places where traffic was not heavy, it was successful, but it does not protect the joints from wear nor does it provide a waterproof surface. The most conservative practice in regard to joint fillers is embodied in the following excerpts from the 1918 Report* of the Special Committee on

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*Proc., Am. Soc. C. E., Dec., 1917, page 2338.

Materials for Road Construction, of the American Society of Civil Engineers:

"As it is desirable to secure waterproof pavements, sand alone should never be used as a joint filler. A bituminous filler may be preferred to a cement-grout filler on account of the lower cost of street-opening repairs, the better foothold provided for horses, and the securing of a more elastic and less noisy pavement.

"Cement-mortar joints when properly made will conduce to integrity of the surface. To insure the best results, a 1 : 1 mix of sand and cement is recommended. Great care is necessary in mixing and applying the mortar or grout. Uniformity in the cement grout, and especially skill and care in its application, are essential to success. To insure uniformity, there should be a constant agitation of the mix, up to the moment of its application, and no more water than is necessary for proper fluidity should be used. Ample time should always be allowed for the grout to set thoroughly before the traffic is admitted to the roadway.

"With bituminous joint fillers, care must be taken to select materials that will not be too brittle in cold weather and so chip out from the joints under traffic, and that will not be so soft in hot weather as to flow out of the joints between the bricks. One of the great difficulties with bituminous fillers of any kind will be that of properly filling the joints between the bricks, and great care must be taken to insure this result."

37. Brick Pavement on Sand-Cement Mortar. Since the year 1916, brick pavements have been constructed by the methods outlined in the preceding articles and also by laying the brick on a sand-cement mortar bed, or green concrete, and filling the joints with cement grout.

The sand-cement mortar bed is usually composed of 1 part of cement to 4 parts of sand. After being spread on the surface of the concrete foundation, it is shaped by a templet drawn forward over the mortar bed, and thoroughly compacted by a hand roller. The bricks are laid as previously described and the joints are filled with cement grout.

38. Brick Pavement on Green Concrete.—A green-concrete foundation is prepared by using a double templet. The forward and lower templet is used to shape the concrete of the foundation. The rear templet is about 2 feet from the forward templet and about $\frac{3}{16}$ inch above it. As the double templet is drawn forwards, a dry mixture of one part of cement and three parts of sand is continuously deposited in the space between the two templets. The striking off of the concrete and the $\frac{3}{16}$-inch coat of mortar thus takes place at the same time. The bricks are laid directly on the green concrete.

39. Maintenance of Brick Pavements.—The repairing of a brick pavement consists mainly in replacing poor bricks, refilling joints, and rectifying any low spots which appear in the surface due to a shifting sand cushion, poor drainage, or poor foundation. When heaving occurs as the result of expansion, the pavement may bulge up and necessitate extensive repairs.

In Minneapolis, where the surface of a brick pavement had become somewhat rough, due either to the uneven wear of the brick or to wear at the edges, a coat of asphalt cement was applied and covered with a layer of screened chips. This coat has not only served to protect the brick from further wear but has also improved the foothold and lessened the noise of traffic.

Where the traffic conditions are not too severe and the pavement has been properly constructed, a brick pavement will wear for a long time with practically no expense for maintenance, provided the forces of contraction and expansion are not sufficient to crack or otherwise injure the wearing course.

STONE-BLOCK PAVEMENTS

GENERAL DESCRIPTION

40. Characteristics.—The chief advantage of a stone-block pavement is its durability. Such a pavement if properly constructed is able to withstand the heaviest kind of traffic and is well adapted for use on those streets that are subjected to the traffic of docking districts. A stone-block pavement is about the only pavement that can be used on very steep grades and furnish a good foothold for horses. In several instances it has been used successfully on grades of 11 per cent. and in one case on a grade of about 19 per cent. The pavement may

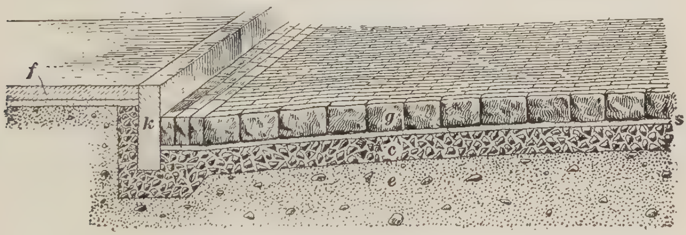


FIG. 8

be somewhat slippery when the stones are rounded off from wear or when a grout filler is used, particularly when the pavement is slightly wet. The chief defect of a worn stone-block pavement is its rough and noisy surface. When in this condition the pavement is not sanitary, since it is hard to clean and the open joints afford a place for the collection of all kinds of filth.

41. Features of Construction.—In Fig. 8 is shown a perspective view of part of a roadway paved with granite blocks on a cement-concrete foundation: *e* is the natural earth subgrade; *c*, the concrete base; *s*, the cushion coat; and *g*, the course of granite blocks. The curb *k* should generally be about 5 inches wide and 18 inches deep; *f* is the sidewalk flagging.

42. Foundation.—The foundation for block pavements should be firm and unyielding, hydraulic-cement concrete being the best material for this purpose. The concrete foundation, or base, should be from 6 to 10 inches in thickness, according to the nature of the traffic; a thickness of 8 inches will sustain a very heavy traffic. The foundation should be well laid and thoroughly tamped, and should be allowed sufficient time to set thoroughly and dry before the paving blocks are laid. The surface of the concrete foundation should be parallel to the surface of the finished roadway.

43. Size and Forms of Blocks.—The paving blocks should be rectangular in form, of uniform depth, and of nearly uniform width. The size of blocks is quite variable. In the United States, large standard blocks for a first-class pavement are from 5 to 8 inches deep, 3 to 4½ inches wide, and from 8 to 12 inches long. The blocks should be perfectly rectangular; those that are wedge-shaped ought not to be allowed in the pavement but should any that are slightly wedge-shaped be permitted, they should be set with their wide edge downwards.

CONSTRUCTION

44. Cushion Coat.—A cushion coat of suitable material should be spread on the foundation to receive the paving blocks. The material for the cushion coat should be of such a nature as to adjust itself easily to the irregularities of the blocks. For this purpose, fine, clean, dry sand is an excellent material; it must be perfectly dry and free from pebbles. It is a well-established principle that moisture must not be present in the foundation, as frost will have a destructive effect on it. The layer of sand should be from 1 to 1½ inches in thickness.

45. Laying the Blocks.—The blocks should be laid in parallel courses; those of the roadway should be laid with their greatest face dimension perpendicular to the axis of the street, while at each outer edge two or three rows of blocks should be set with their longest edges parallel to the curb to form the gutter. The blocks of each course should all be of the same

width, and their lengths should be so arranged as to break joints with the adjacent courses. The blocks should be laid singly, stone to stone, with the least possible width of joints, the courses being begun at the gutters and laid toward the middle.

At the intersection of cross or connecting streets, the blocks must be laid diagonally; otherwise, ruts will be speedily formed. The most approved method of laying rectangular blocks of stone, wood, brick, or asphalt at street intersections is shown in Fig. 9.

46. Ramming.—After the blocks are set, they should be thoroughly settled into the sand cushion by ramming them

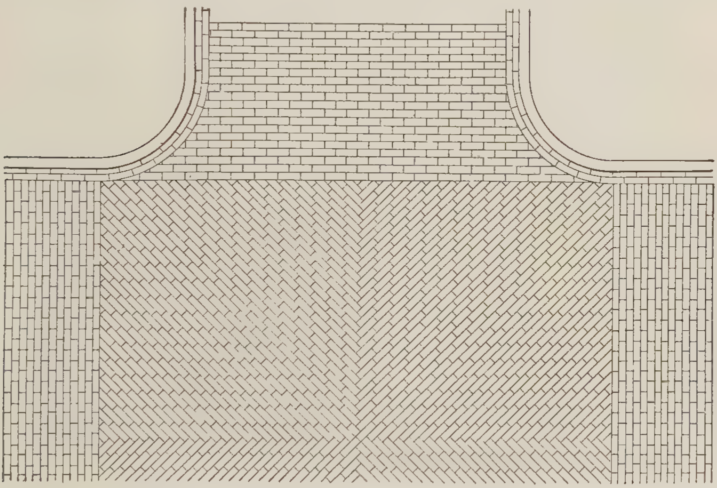


Fig. 9

with a ram weighing not less than 50 pounds and having a bottom diameter of not less than 3 inches. Stones that sink below the general level should be taken up and the sand bedding increased sufficiently to bring them to the required height. As the work progresses, the workmen doing the ramming should keep at a distance of at least 25 feet back from the front row of blocks that is being laid.

47. Joint Filling.—Sand, tar and gravel, pitch, asphalt, and cement grout are used to fill the joints of the stone-block

pavement. The object of the filler is to make the pavement waterproof, to fill completely the joints in order to eliminate recesses in which filth might collect, and to protect the edges of the block. Sand alone should not be used, as it does not perform any of the functions of an efficient filler.

Tar and gravel, tar pitch, asphalt and bituminous mastics have all been satisfactorily used for fillers. It is absolutely necessary, however, that the bituminous filler should possess such properties that it will not soften to the point of flowing in summer nor harden in winter so that it will be brittle and chip out under the blows of horses' feet. The use of a bituminous filler makes the pavement less noisy than when a cement-grout filler is used and enables repairs to be made at a minimum cost, as the blocks may be readily removed.

Cement-grout filler, when properly mixed and applied, has given very satisfactory results from the standpoints of producing a sanitary pavement and protecting the edges of the blocks. However, it materially increases the slipperiness of the surface and makes repairs for street openings expensive and difficult, as the blocks have to be broken up in order to remove them, and it is impracticable, in many cases, to keep traffic off the repairs until the grout has set. Many granite-block pavements improperly filled with grout have become rough within a few years, due to the rapid chipping out of the cement grout by the blows of horses' feet.

48. Maintenance.—The maintenance of properly constructed stone-block pavement is negligible for a few years. When the blocks become worn so that the surface is extremely uneven, it is possible to take the blocks up, redress them, and relay them as a new pavement. Since 1908, worn out blocks have been recut and used again economically. For instance, if the original blocks were $3\frac{1}{2}$ to 5 inches wide, 5 to 7 inches deep, and 10 to 12 inches long, the recut blocks would be of the same width, but 5 to 6 inches deep and 5 to 7 inches long. Other details of maintenance of stone-block pavements are similar to those described for brick pavements.

SPECIAL CONSTRUCTION METHODS

49. Trackways.—Trackways have been built, both in this country and abroad, of stone slabs, brick, concrete blocks, steel shapes, and other materials. Stone trackways were used on one of the toll roads in New York State as early as 1831. The slabs, which measured 24 inches in width by 4 inches in thickness, were laid with a gauge which would accommodate the vehicles. The space between them was paved with cobblestones. Trackways of rectangular stone blocks, about 12 inches wide, 6 inches thick, and of varying lengths, have been used in some cities of England and Scotland on steep hills or where the traffic is exceptionally heavy.

50. Durax, or Kleinpflaster.—Pavements made of small stone blocks, and known as Durax or Kleinpflaster,

FIG. 10

have been laid to a considerable extent in Europe, the name Durax being used in England and Kleinpflaster in Germany. The principal feature of such pavements is the small irregular size of the blocks, which approximate cubes $2\frac{1}{2}$ to 4 inches in size. They are sufficiently irregular both in size and in shape to permit them to be laid in arcs of circles of comparatively small radii, as shown in Fig. 10, and so that the joints will not be excessively large. By laying the courses in circular arcs, few of the joints are parallel to any line of traffic. They have been used to a slight extent in cities in the United States.

PAVEMENTS MADE OF WOOD AND OTHER MATERIALS

WOOD-BLOCK PAVEMENTS

51. Size and Arrangement of Blocks.—Many methods of constructing wooden pavements have been tried, and a number of systems have been patented. The different systems vary with regard to the forms of blocks, of which a great variety have been used. By far the greater number of these systems have proved unsatisfactory, and at present it is quite generally accepted that the best, as well as the simplest, form of wood pavement consists of rectangular blocks set on a solid foundation, with the fibers vertical.

A properly constructed wood-block pavement, built with blocks that have been treated with a preservative, makes an excellent pavement which is durable under heavy traffic. It is much less noisy than a stone-block, brick, or sheet-asphalt pavement. Some teamsters object to a wood-block pavement on account of its slipperiness. It is only fair to state that this condition is noticed principally at times when the pavement is in a slightly moist condition, but under the same conditions it is probably not much more slippery than a sheet-asphalt pavement. When too much preservative fluid has been used in treating the blocks, some inconvenience and unpleasantness is very liable to be experienced due to *bleeding,* that is, some of the preservative oozing out on the surface of the blocks. If properly constructed, wood-block pavement presents a smooth surface which is readily cleaned.

52. Foundation.—A solid unyielding foundation is as essential to a satisfactory wood-block pavement as to any other kind; in the United States, however, the early wooden pavements were very commonly constructed with insufficient and

unsuitable foundations. In some cases, the blocks have been set either in a layer of sand spread on the natural earth foundation or on a layer of sand laid on plank. Such foundations do not sufficiently protect the subsoil, but allow the water to penetrate until the soil becomes saturated and yielding. In this condition, it cannot furnish a firm and solid support to the paving blocks, but will allow them to settle unevenly under the traffic, causing the surface of the pavement to become very rough and uneven.

A solid, unyielding, and impervious foundation that will not only distribute the weight of the concentrated loads over a sufficient area of the natural foundation, but will also protect the foundation from becoming saturated and unstable, is absolutely essential to the stability and permanence of any pavement. Hydraulic-cement concrete forms the best foundation for this purpose. But, as wood-block pavements are not adapted to such heavy traffic as are granite-block pavements, the foundations for the former need not generally be of so great depth; a layer of concrete 6 inches in thickness will in many cases be sufficient for the foundation of wood-block pavements.

53. Form and Size of Blocks.—Most of the wood blocks are rectangular in shape and are so cut that a smooth pavement can be laid with the rows of blocks of uniform width. To secure the desired results, it is necessary that the allowable variations in dimensions of the blocks be carefully specified. Blocks vary in depth from 3 inches for light traffic to 4 inches for heavy traffic. For a given pavement, only $\frac{1}{16}$ inch variation in depth is allowed in some cities. Widths of blocks vary from 3 to 4 inches, $\frac{1}{8}$ inch variation being allowed for a given section of pavement. Blocks vary in length from 5 to 10 inches.

CONSTRUCTION AND MAINTENANCE

54. Cushion Coat.—The cushion coat for a wood-block pavement is generally composed of either 1 inch of dry sand, $\frac{1}{2}$ inch of cement mortar, or a thin layer of bituminous cement.

When sand is used, it should pass a $\frac{1}{4}$-inch screen and contain from 10 to 25 per cent. of loam or clay. The cushion is spread in a layer over the concrete base, and the blocks are then bedded in it.

55. Laying the Blocks.—Rectangular blocks should be set close together in parallel courses with their lengths perpendicular to the axis of the street or the direction of the travel. The blocks in each course should break joints with the blocks of the adjoining course by a lap of not less than 2 inches. Adjacent to each curb, about three courses of blocks are sometimes laid parallel to the curb to form the gutter. Usually a space 1 inch in width adjacent to each curb is provided for an expansion joint which is filled with bituminous cement. The

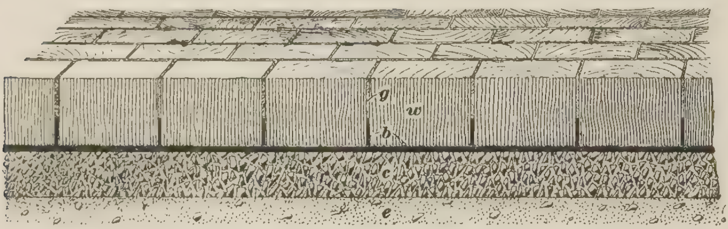


FIG. 11

blocks are compacted by rolling with a tandem roller of from 3 to 7 tons weight until the surface becomes smooth and conforms with the required crown of the roadway.

56. Filling the Joints.—Different materials and various methods are employed for filling the joints of wood pavements, and with varying results. The joints are sometimes filled with a grout composed of 1 part of Portland cement and 1 to 2 parts of fine, clean, sharp sand. Fillers of tar pitch and asphalt are used in many cities of the United States. Fine sand has been used successfully in some cases. The wood pavement is finished by covering its surface with a thin coating of sand.

In Fig. 11 is shown part of a street pavement of rectangular wooden blocks on a concrete base; *e* is the natural earth subgrade; *c*, the concrete base; *w*, the wooden blocks; *b*, a bitu-

minous or asphaltic-cement cushion coat and joint filling; and *g*, a joint filling of hydraulic-cement grout.

57. Maintenance.—One of the principal troubles with wood-block pavements is the oozing out of the preservative fluid, particularly during warm weather. This bleeding is attributed to one or more of the following factors: the character and quality of the preservative fluid used; the effect of traffic; the expansive effect of heat on the blocks; and the use of too much preservative fluid per cubic foot. The pavement while in the condition mentioned is extremely objectionable, but it generally proves satisfactory after two or three years, when the bleeding usually ceases. As a remedy against bleeding dry sand should be applied in a thin covering, and when it becomes saturated with the oil should be scraped off.

The other maintenance work required consists of removing poor blocks, and of raising low spots and lowering the pavement in places that have bulged up. The bulging up of certain places can generally be attributed to the lack of adequate expansion joints. This fault is accentuated if the blocks absorb water to any great extent.

During wet and frosty weather it will be frequently necessary to spread a light coating of sand over the pavement in order to prevent it from becoming slippery. In France and England, wood pavements have been covered with a bituminous surface to reduce slipperiness and preserve the surface.

MISCELLANEOUS ROADS AND PAVEMENTS

SHELL ROADS

58. Method of Construction.—In many of the Southern states, stone and gravel suitable for road surfaces do not exist, and can only be procured at a prohibitive cost. As a substitute, oyster shells, which can be had in abundance and at a very low cost, are used. These shells, when the road is carefully maintained, form an excellent surface for light traffic.

The earth surface of the roadway is graded and finished to a suitable form, and provision for its drainage is made where necessary. The shells are spread loosely over the prepared surface, and under the action of the traffic they are speedily crushed and compacted into a smooth surface. To keep such a road in good condition requires constant watchfulness. When ruts or depressions occur, they must be filled up with broken shells, and the ditches and drains must be kept clear so as to afford a free passage for water.

59. Good results with the use of shells can be obtained by following the methods used by the Maryland State Roads Commission. The specifications stipulate that the subgrade shall be firm and well rolled. The depth of the first course of shells laid loose is either uniformly 5 inches, or 5 at the center and 3 at the sides. The depth of the second course is either uniformly 3 inches, or 5 at the center and 3 at the sides. The shells are spread upon the roadbed with shovels from piles along the road or from a dumping board, then rolled with an 8-ton roller, and sprinkled with water or bound with sand during the process of rolling until the surface is firmly compacted. The third course is composed of clean, sharp sand, spread just thick enough to cover the compacted second course. Shell roads, unless watered or treated with some form of dust palliative or bituminous surface, are liable to be very dusty.

CORDUROY ROADS, COBBLESTONE AND SLAG-BLOCK PAVEMENTS

60. Corduroy Roads.—Roads built of poles or logs laid across the roadway are called corduroy roads, because of their corrugated or ribbed appearance. These roads should never be built where it is possible to secure any other good material, except in cases of emergency, such as when it is necessary to build a temporary road for the moving of artillery and commissary trains through swampy regions in time of war. Logs are superior to poles for this purpose, and should be used when possible.

61. Cobblestone Pavement.—A cobblestone pavement consists of cobblestones of nearly uniform size embedded in sand. The roadway is excavated to the required depth and form, and on this foundation is spread a layer of clean sand or fine gravel not less than 10 inches in thickness. In the bed of sand or gravel are set small round boulders or field stones; they are set on their small ends, with their greatest dimension vertical. The stones are generally from 4 to 8 inches in horizontal dimensions, the small stones being placed in the center and the large ones on the sides of the roadway. After the stones are set, they are rammed with a heavy ram until they

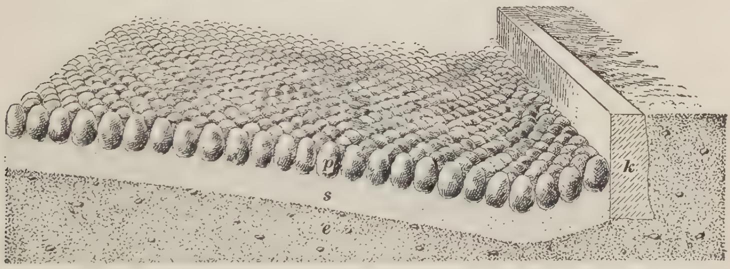


FIG. 12

have settled to a firm and solid bearing in the bed. After the pavement is thoroughly rammed, a layer of sand or fine gravel about 2 inches in thickness is spread over it.

A portion of a cobblestone pavement is shown in perspective in Fig. 12, in which *p* is the pavement of cobblestone; *s*, the bed of sand or gravel; *e*, the natural earth foundation; and *k*, the curb.

62. Slag Roads.—Blast-furnace slags are produced in the manufacture of iron and steel, and in some cases are very similar in appearance to close-grained igneous rocks. Slag is used for foundation courses and in some instances to form the entire road crust. The methods employed in construction are similar to those described for broken-stone roads.

63. Slag-Block Pavement.—Molded slag blocks have been used in England and the United States for the construction of pavements. The details of construction of slag-block

pavements are similar to those used in the construction of stone-block pavements. Careful culling of the blocks is required in order to reject those that contain blowholes. In many blocks these blowholes are not visible on the surface, but are soon disclosed under the action of horse-drawn vehicle traffic.

DUST PREVENTION, STREET CLEANING, AND SNOW REMOVAL

DUST PREVENTION

INTRODUCTORY

64. Dust Laying in Its Relation to Street Cleaning.—Public health, safety, and convenience require that roadways should be kept clean. The close relationship existing between dust laying and street cleaning is obvious. On certain types of roadways, such as those made of earth, gravel, or broken stone, the problem is a combination of cleaning and dust laying; after the surface is cleaned, dust remains, which must be treated to prevent its being a nuisance. On such pavements as brick, cement concrete, wood block, bituminous macadam, bituminous concrete, and sheet asphalt, only methods of cleaning need to be considered, and they should be such as will remove all distributable dust. Thus it will be seen that the method of cleaning depends primarily on the kind of roadway.

65. Various Effects of Dust.—The ways in which dust acts as an enemy to the public welfare may be summarized as follows: (1) The action of traffic may form heavy dust clouds to such an extent as to obscure a view of the roadway. (2) When wet, the formation of mud may cause skidding of wheels and dangerous footing for both man and beast. (3) Real estate values may be lowered where dust occurs in large quantities. (4) It soils clothing and other personal

property. (5) It acts as an abrasive agent upon certain surfaces. (6) It has a harmful effect on plant life. (7) It acts as a distributor of disease germs.

DUST LAYERS AND PALLIATIVES

66. Classification.—Dust layers that are in common use include water, sea-water, salt solutions, calcium chloride, tar and oil emulsions, light oils, and light tars. As oils and tars are included in this classification, the distinction between treatments with palliatives and the construction of bituminous surfaces should be noted. Palliatives are materials that temporarily prevent the formation or dispersion of dust, while bituminous surfaces consist of superficial coats of bituminous materials, with or without the addition of stone or slag chips, gravel, sand, or materials of a similar character. It is evident, therefore, that the continued use of palliatives may result in the formation of a bituminous surface, and hence it is difficult to draw a line of distinction between the treatment with palliatives and the construction of bituminous surfaces. However, a surface is usually considered to be a bituminous surface only when it is so constructed as to be effective for 6 months to 2 years.

67. Water.—Water is an effective dust layer when properly applied under the direction of engineers who supervise the details of the method of application. Watering carts must be used with which water may be distributed uniformly and in small amounts per square yard of roadway. Instead of flooding the surface, it should only be dampened. Dependent upon climatic conditions and local peculiarities of a given street, such as the character of the roadway surface, shade trees, buildings, etc., from one to eight applications per day will be required to lay the dust and keep the street from being objectionably dusty.

68. Sea-Water.—The use of sea-water has not been developed sufficiently to establish its value and rating as a dust palliative. In one case it was found that sea-water was

about three times as effective as fresh water in preventing dust and, when properly applied, had no injurious effects on the surface of the roadway.

69. Calcium Chloride.—Calcium chloride is a by-product in the ammonia-soda process of manufacturing common washing soda and in other industrial processes. It is applied by both the wet and the dry methods. When applied dry to the cleaned road surface, from $\frac{3}{4}$ to $1\frac{1}{2}$ pounds per square yard is used for one application. Usually two applications per season in the North will give good results on light-traffic roads. When applied wet, the calcium chloride is dissolved at the rate of 1 pound to 1 gallon of water, and about $\frac{1}{3}$ gallon of solution is used per square yard. To secure freedom from dust about ten applications should be used per season.

70. Emulsions.—Dust layers belonging to the emulsion class consist of water with some saponifying agent and an asphaltic oil. Tar is sometimes, though rarely, used. The saponifying agents most commonly used with oils are alkalies, such as potash, soda, and ammonia; crude carbolic acid, and cheap soap solutions are also used. These substances form chemical solutions with which the oils can be mixed, and when the mixture is spread upon the road surface, the water quickly evaporates, leaving the oil in a thin evenly spread layer. Distribution is usually made with an ordinary watering cart. From six to ten treatments are used in a season extending from April to October.

71. Light Oils and Light Tars.—Usually, light oils and light tars are applied cold, by use of ordinary sprinkler carts or distributors. In order that distribution shall be economical and satisfactory, pressure distributors should be used that are equipped with suitable hoods to protect pedestrians and property from the fine spray accompanying distribution, and that are capable of distributing the material in as small amounts as $\frac{1}{8}$ gallon per square yard. Light oils and light tars are effective for 6 weeks to 2 months if properly applied. The amount used per square yard should be from $\frac{1}{5}$ to $\frac{1}{8}$ gallon, depending on the kind of material and the condition of the

surface of the roadway. If more than this amount is used, a soft, greasy surface will result and the oil may work down into the wearing course and, serving as a lubricant, may cause disintegration by the formation of a loose surface. Such oils or tars should not be employed after November 1 in the Northern states, as a muddy, greasy surface would probably form on the roadway during a part of the winter.

STREET CLEANING

DUST AND DIRT REMOVAL

72. Classification of Cleaning Methods.—Earth, gravel, and broken-stone roadways are cleaned by gangs or

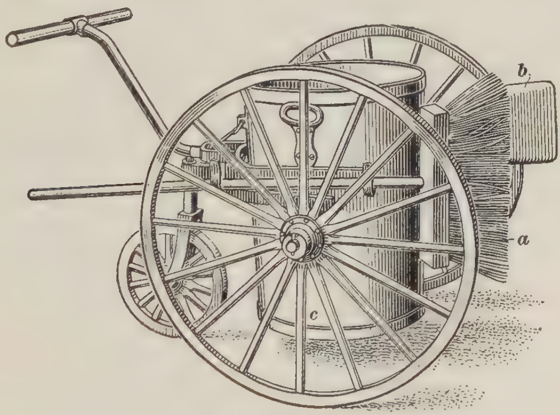


FIG. 13

patrolmen with push brooms or by horse-drawn or motor-driven rotary sweepers preceded by sprinkling. Bituminous surfaces and good brick, bituminous, and wood-block pavements are cleaned of coarse dirt by gangs or patrolmen, followed closely by hose flushing and squeegeeing or by rotary scrubbers. Brick in poor condition and stone-block pavements are cleaned by gangs or patrolmen. Rotary brushes and hand or machine flushing methods may also be employed to

advantage. In all the methods, the dirt is forced to the gutters and immediately removed by gangs with wagons following closely.

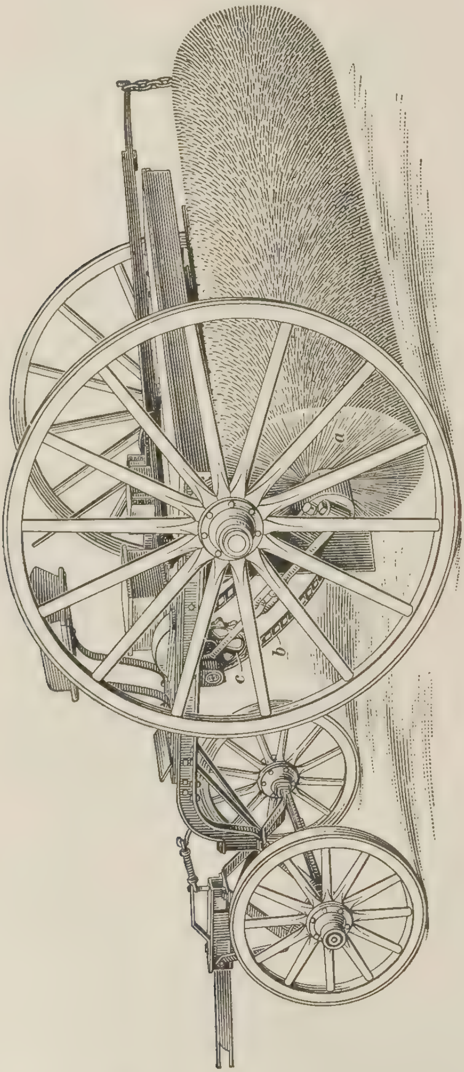


Fig. 14

73. Street-Cleaning Equipment.—The principal appliances and machines employed in street-cleaning work are as

follows: push brooms, shovels, can or bag carriers, rotary sweepers, rotary scrubbers, flushing machines, and combined sprinklers and scrubbers.

The laborers, who are formed into gangs, or the patrolmen, are each furnished with the equipment shown in Fig. 13, consisting of a push broom *a*, a shovel *b*, and a portable can carrier *c*.

The rotary sweeper, or machine broom, Fig. 14, consists of a four-wheeled, horse-drawn vehicle provided with a rotary broom *a*. The latter should have a wooden shaft and split-

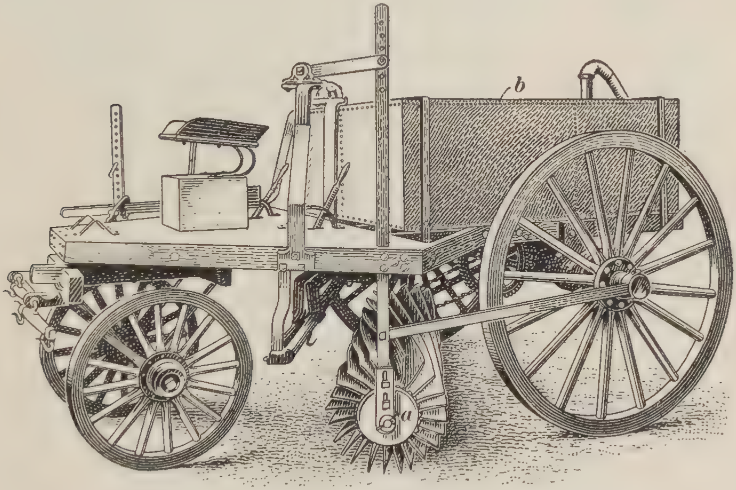


Fig. 15

bamboo bristles about 12 inches long. The shaft is set obliquely and driven by the chain belt *b* from a sprocket *c*.

74. A horse-drawn squeegee cleaning machine is shown in Fig. 15. At *a* is the cleaning roller driven from the rear axle by sprocket and chain. The roller has a steel shaft on which are fastened a number of rubber spiral fins. The tank *b* contains about 500 gallons of water, and at the rear there is a sprinkler used in combination with the revolving roller.

75. An automobile flushing machine is shown in Fig. 16. Usually it is mounted on a chassis having a capacity of not

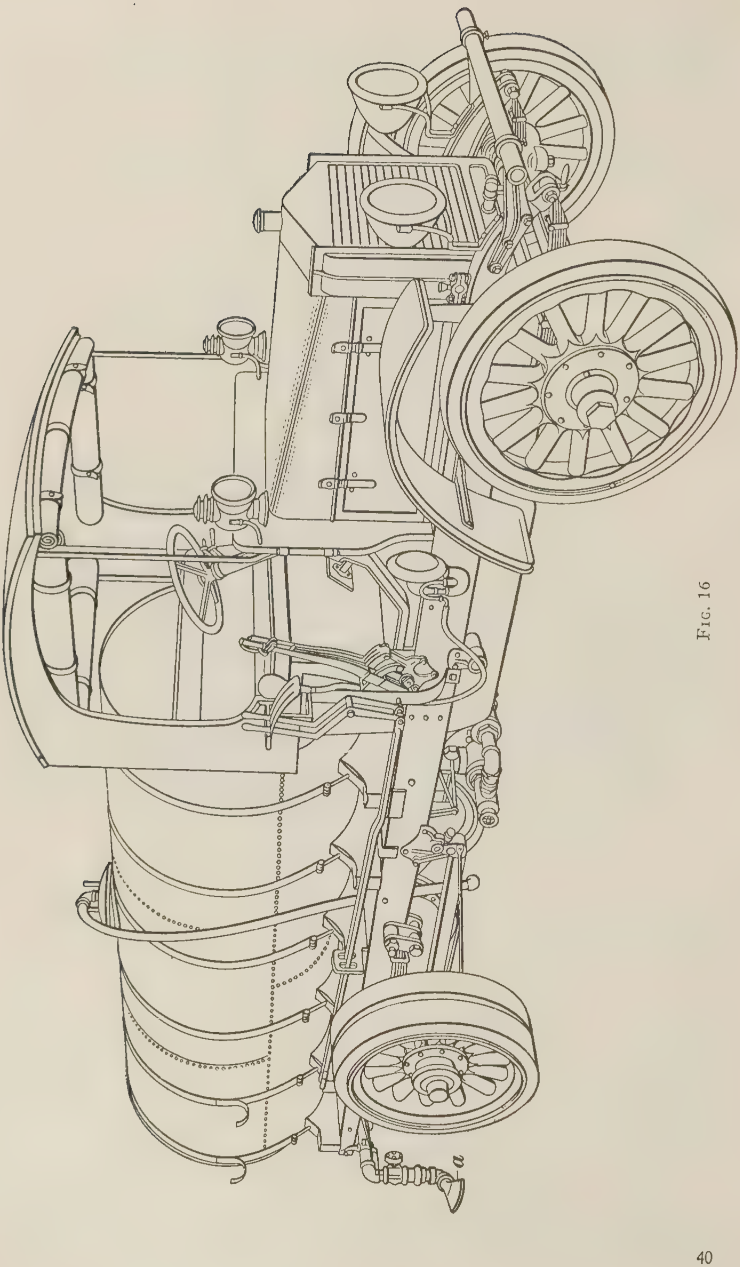


FIG. 16

less than 5 tons, and has a water tank holding at least 1,200 gallons. Preferably it should have motor-driven pumps supplying air under pressure to the tank, in order that the water may be discharged from the nozzles with a pressure of from 35 to 60 pounds per square inch. The nozzle *a* is elongated and so constructed that it may be set in any required position.

76. Hand Cleaning.—Hand cleaning is done either by gangs or by patrols, usually during the daytime. In the first-named method the roadway is cleaned at frequent intervals, while in the latter case a patrolman has a certain district to clean each day. Each patrolman has a push broom, shovel, and can or bag carrier in which to collect the refuse. The principal disadvantage of the gang method is that the streets are in an objectionable condition for the greater part of the interval between consecutive cleaning operations.

77. Machine Sweeping.—Generally, rotary sweepers are employed at night. Such sweeping should always be preceded by sprinkling to insure the laying of the dust. There are numerous combined sweepers and sprinklers, both horse-drawn and motor-propelled. Sweeping with such apparatus alone is efficient on streets subjected to light traffic, but on the heavier-traveled thoroughfares it should be supplemented by hand sweeping during the day.

78. Hose Flushing.—Flushing is accomplished by applying a stream of water to the surface with a broad, sweeping motion. In addition, the pavement is scrubbed with rubber squeegees worked by hand to remove any adhering solid matter. The material is carried in suspension to the sewer through the nearest catch-basin. This treatment is particularly efficacious in removing all fine dirt, but it necessitates the preliminary removal of all coarse material that would be likely to clog the sewers.

79. Machine Scrubbing and Flushing.—Sprinkling combined with the use of a rotary scrubber, or squeegee, is satisfactorily used on smooth pavements for the removal of dust. Some machines are equipped with attachments for

sprinkling the pavement just in advance of a rotary squeegee. There are also various types of flushing machines used on sheet and block pavements which throw the water in broad, fan-shaped sprays over the surface, thus washing the dirt into the gutters and eventually into the sewers.

SNOW REMOVAL

80. General Methods.—The methods used in dealing with snow on highways are influenced to a great extent by climatic conditions. In places where the snowfall is very heavy and low temperatures are constant, it is not so much a question of removing the snow as it is of making the highways passable. The drifts are cut through or smoothed out and the whole roadway is compacted by a light roller. In practically all large cities, it is the practice to remove the snow from the business districts as soon as possible. This practice is also being followed in the case of trunk highways connecting cities. If not efficiently removed, a heavy snowfall will not only cause extreme inconvenience to the public, but it may seriously impede and hinder the traffic and business of a community.

81. Snow-Plow Outfits.—As a general rule, the streets on which car tracks are located are cleaned first. The traction companies naturally try to keep the cars moving, and the snow no sooner begins to fall than special cars, equipped with brushes or plows, are sent over the different lines to clear the tracks. It is this principle of starting work of removal before the snow attains much depth that makes their efforts so uniformly successful. The work done by the traction companies is of the utmost assistance to vehicular traffic. In many cities, after a heavy fall of snow, the cleared trackway is the only place that is accessible for vehicular traffic.

Fig. 17 shows a front view of a motor-truck plow or road scraper, generally of 5 tons capacity. The plow blade *a*, which is about 10 feet long and 1 foot deep, is attached to a sector *b*, which allows the plow to be adjusted at any desired angle,

usually 45 degrees. The chains *c*, attached to the motor front, support the plow and, being provided with springs, give it a certain amount of freedom in adjusting itself to high and low places in the roadway. These plows are sometimes used in pairs, one being at one side and just behind the other in such a way as to clear two widths in one passage.

82. In Fig. 18 are shown a plan, side elevation, and rear view of a horse-drawn plow, usually drawn by four horses

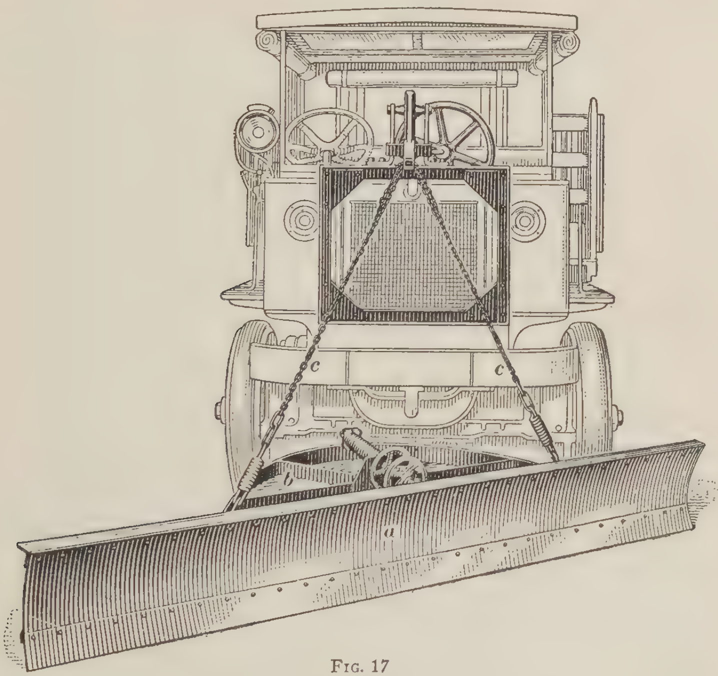


FIG. 17

and manned by two drivers and one operator. These **V**-shaped plows are used extensively to clean a path for vehicles on highways not occupied by car tracks. Rotary brushes can be successfully used to remove light falls of snow. In Paris these sweepers are used for snowfalls from $\frac{1}{2}$ to 1 inch in thickness.

83. Final Removal of Snow.—By the use of machines and gangs of men using shovels and push pans, the snow is

placed in piles in the center or near the sides of the roadway, as local conditions, such as the width of roadway, location of car tracks, etc., permit. In light storms the large separate piles are removed by wagons. When drifts are large, they are removed by wagons without previous piling. The snow is taken by the wagon to some natural waterway, or dumped on vacant lots, or under certain conditions discharged through

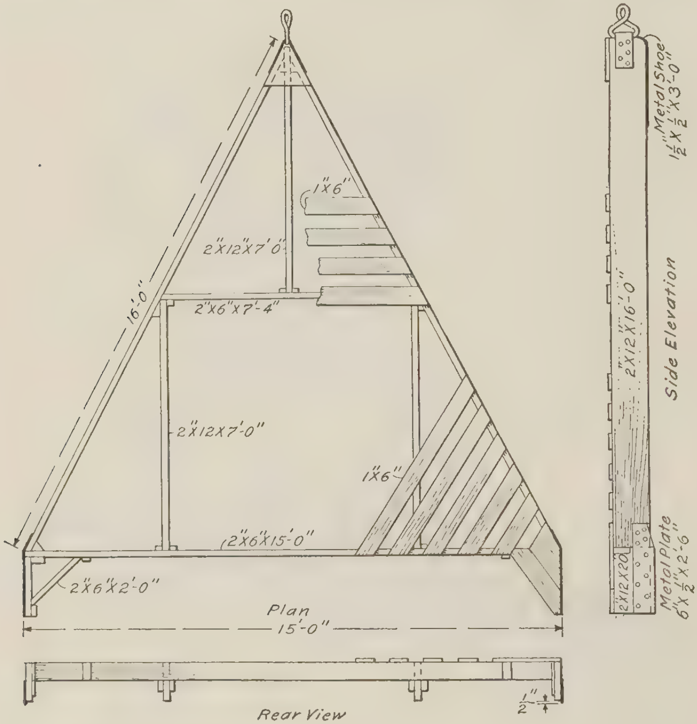


Fig. 18

manholes into the sewers. Although various machines have been devised for the purpose of melting snow, none of them has been successful, as least from an economical standpoint.

84. Removal of Snow by Flushing.—The practice of flushing is quite common in many European cities. Flushing is not carried on when the temperature is below the freezing point on account of the danger of ice forming in the sewers.

SIDEWALKS, GUTTERS, AND CURBS

SIDEWALKS

GENERAL DESCRIPTION

85. Essential Requirements for Sidewalks.—Footwalks for the accommodation of pedestrians are placed along both sides of streets, between the curbing and the property line; such footwalks are commonly called *sidewalks*. There are several essential qualities that a sidewalk should possess. The surface should be smooth, non-slippery, non-porous, agreeable in color, low in first cost and annual cost, easy to clean, and constructed of a material that will wear well. When used on a business street, the material should be sufficiently strong to resist the shocks from falling objects, and of such a character that repairs can be easily made. In general, a good sidewalk designed for pedestrian traffic should possess the same essential qualities that are necessary for a good pavement designed for vehicular traffic.

86. Widths and Heights of Sidewalks.—On business thoroughfares, the entire space between the curbing and the building line is usually occupied by the sidewalk, which commonly consists of stone or other substantial material. The edge of the sidewalk adjacent to the curbing is always placed at the same elevation as the curbing—that is, at the street grade—but the edge adjacent to the building is elevated somewhat above this, so as to give a slight inclination toward the gutter for drainage.

On residence streets, the construction of sidewalks does not follow any rigid rule; their widths are generally about one-fifth to one-sixth the width of the roadway, or from about 5 to 10 feet. The inside edges of the sidewalks on residence

streets are commonly placed about 2 feet from the property line.*

The sidewalks of residence streets are generally placed at the street grade wherever the natural cross-section of the street is sufficiently level for this to be done without inconvenience or disadvantage to the adjoining property. It is decidedly the best practice to put all sidewalks either at the street grade or at a certain small fixed distance, 3 or 4 inches, above grade; this is especially true of the sidewalks of paved streets. In many cities, however, the elevations of the sidewalks on residence districts are varied materially from the street grades, wherever such variation will better accommodate the adjoining property. This is illustrated in Fig. 19,

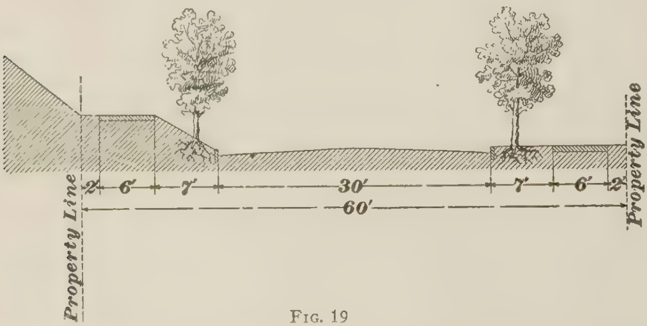


FIG. 19

in which, in order to accommodate the elevated position of the adjacent property, the sidewalk on one side of the street is elevated considerably above the surface of the roadway. Such practice should be avoided whenever possible, as the resulting appearance of the street is not nearly so good as when both sidewalks are placed at grade. However, this is a matter that is not usually left wholly to the discretion of the municipal engineer, but is often regulated by city ordinance, or, possibly, by some provision of the city charter.

* The boundary line of a street, or the dividing line between the street and the adjoining property, is known variously as the property line, building line, block line, fence line, and, sometimes, street line, though the latter term is more commonly applied to the center line of the street.

87. Lateral Slopes of Sidewalks.—For the purpose of drainage, sidewalks should have a slight lateral slope toward the curb. On business streets that are closely built up, in which the entire width between the curb and the building line is occupied by the sidewalk, this lateral slope of the sidewalk will fix the elevations on the building line The edge of the sidewalk next to the curb will be placed at the elevation of the curb, that is, at the street grade, and the edge of the sidewalk adjacent to the building line will be higher or above grade an amount equal to the width of the sidewalk in feet multiplied by the lateral slope per foot. Lateral slopes of from $\frac{1}{8}$ to $\frac{1}{2}$ inch per foot are in common use. A slope of $\frac{1}{4}$ inch per foot, however, is generally very satisfactory for this purpose.

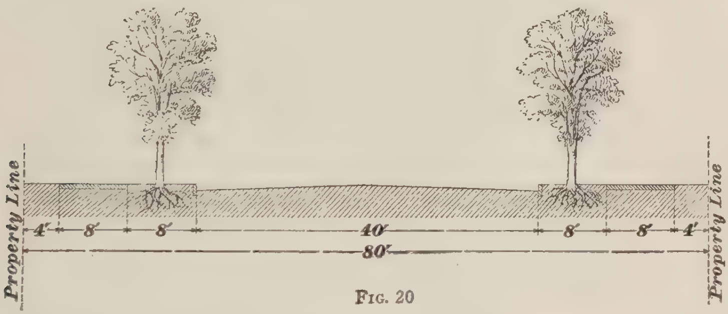


Fig. 20

All that portion of the street between the curb and the property line should have this uniform lateral slope, whether wholly occupied by the sidewalk or not.

88. Street Lawns.—Those portions of a residence street not occupied by the roadway and sidewalks should be laid out as lawns, with at least one row of trees on each side of the roadway. In Fig. 20 is shown the cross-section of a residence street 80 feet wide, having a roadway 40 feet in width and two sidewalks each 8 feet in width. A single row of trees is shown on each side of the roadway, between the sidewalk and the curbing. With these widths, however, if the residences are set well back from the property line, another row of trees could be advantageously introduced between the sidewalk and the property line.

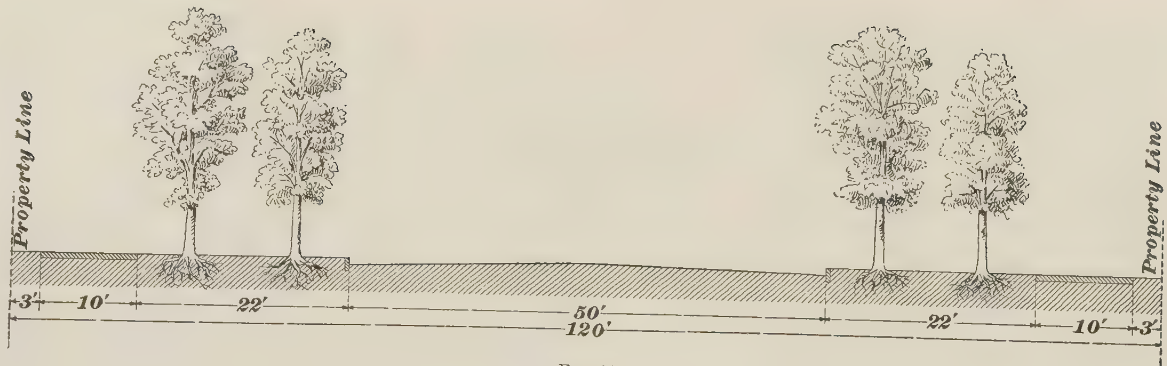

Property Line
3′
10′
22′
50′
120′
22′
10′
3′
Property Line

Fig. 21

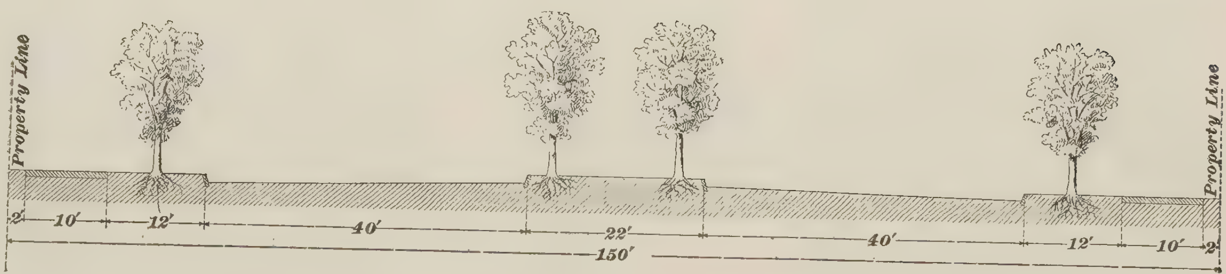

Property Line
2′
10′
12′
40′
22′
150′
40′
12′
10′
2′
Property Line

Fig. 22

In cases where the lawns are of liberal widths, two rows of trees are sometimes set along each side of the roadway between the sidewalk and the curbing, as shown in Fig. 21, which represents the cross-section of an avenue 120 feet wide, having a roadway 50 feet wide and two sidewalks each 10 feet wide. The arrangement there shown is generally well adapted to avenues of this width. In some cases, the sidewalk is nearer the curbing, leaving most of the lawn space between the sidewalk and the property line This is not so good an arrangement as that shown in Fig. 21, however, because the position of the sidewalk is neither so pleasant for pedestrians nor so conveniently accessible to the residences. Very broad avenues sometimes have two roadways, separated by a lawn extending along the center of the avenue and containing one or two rows of trees. Such avenues are commonly called boulevards. The cross-section shown in Fig. 22 is somewhat similar to that of the Western Boulevard in the city of New York.

The importance to a city of clean and well-kept lawns can scarcely be overestimated. They serve not only as a means of ornamentation, but also as a means of purifying the air, and thus have a beneficial effect on the health of the inhabitants. Pure air is none too plentiful in a crowded city, and one of the most effective purifying agents is healthy growing vegetation, such as trees and clean grass.

CONSTRUCTION OF SIDEWALKS

89. Materials of Construction.—The materials generally used for sidewalks are as follows: natural and artificial stone, brick, asphaltic mastic, sheet asphalt, cement concrete, gravel, and wooden planks.

90. Stone Sidewalks.—Stone sidewalks are generally durable and satisfactory; sandstone, limestone, slate, and granite are employed. Of these, a good quality of sandstone gives satisfactory results; when of compact texture, it absorbs comparatively little water, and soon dries after rain; it also wears well without becoming very slippery. Limestone does

not usually wear so well. Granite, though it wears exceedingly well, becomes very slippery.

The slabs or flagstones should be not less than 3 inches thick and of uniform thickness throughout; each stone should contain not less than 10 square feet of superficial area; the top should be cut evenly, and the edges should be dressed square throughout the full depth of the stone. The flagstones should be laid on a bed of sand or clean, gritty gravel; they should be well bedded in the sand foundation and settled to a solid, even bearing. The joints should be closed with hydraulic-cement mortar.

91. Cement-Concrete Sidewalks.—Cement concrete is extensively used for paving sidewalks. When the materials are good and the work is properly done, this form of sidewalk is one of the best. These sidewalks are constructed in one of two ways, namely, from slabs of the artificial stone manufactured at a factory and laid in the same manner as natural stone, or by forming the artificial stone in its proper position in the footway; the latter is the plan more commonly adopted.

Several varieties of artificial stone are used; the process of manufacture is practically the same for all kinds, the difference being due to variations in the materials employed and the proportions used. Portland cement, sand, gravel, and broken stone are the materials commonly employed.

92. When the artificial stone is manufactured in place in the walk, the process should be substantially as follows: The ground should be excavated to a depth of not less than 8 inches below the intended surface of the finished pavement, and to such greater depth as may be necessary to secure a solid foundation and remove all perishable material. Where the excavation is deeper than 8 inches, the additional depth should be filled with suitable material, as sand or cinders, and the entire surface of the excavation should be well compacted by ramming. On this foundation should be spread a layer of gravel, cinders, clinker, broken stone, or similar material, which should be well consolidated so as to have a finished thickness of about 4 inches. On this should be spread a layer

of hydraulic-cement concrete, the composition of which may be as follows:

Material	Parts by Measure
Portland cement	1
Sand	2 to 3
Gravel, broken stone, or broken slag	5 to 7

This concrete should be laid in molds to form blocks or sections 5 to 10 feet square. The side and cross pieces of the molds are usually made of $\frac{1}{2}$-inch boards. The molds should be set on the gravel or cinder foundation, adjusted to the required grade and slope, and securely staked in place.

93. The base, or first layer of concrete, should have a thickness of from 1 to 5 inches when thoroughly consolidated by ramming. After the concrete has partly set, it should be covered with a wearing coat, $\frac{1}{2}$ to 1 inch thick, composed of equal parts of Portland cement and clean, sharp sand. The surface should be neatly troweled to the proper grade.

Before the wearing coat is spread, the cross pieces of the molds should be removed; this will leave joints about $\frac{1}{2}$ inch wide between the blocks of concrete, which in some processes are filled with sand or tar, and in others are left open. The wearing coat is then laid as a monolith and joints are often cut in it with a sharp-bladed tool directly over the joints in the base. In the more common practice, sheets of tar paper are placed on the inside of the cross pieces; in this method, the cross pieces in one section are removed before the concrete is placed in the adjacent section, thus forming tar-paper joints between the blocks or sections.

The pavement should be kept damp by frequently sprinkling it with water for a period of at least one week, and should also be protected from the heat of the sun by a covering of damp sand. Travel should be kept off the pavement for about 10 days, or until the concrete has thoroughly set.

94. Brick Sidewalks.—Bricks of suitable quality, if carefully laid on a proper foundation, form an excellent footway pavement for the streets of residence and suburban districts, and also for the main streets of small towns. Selected

paving brick should be used, and the brick should be of suitable quality and of uniform size and texture. While what are known as vitrified paving bricks, used for roadway paving, make the best sidewalk bricks, those commonly used are simply very hard-burned building bricks.

For the best construction, a foundation of hydraulic-cement concrete should be prepared. The more common construction, however, is generally about as follows: The ground is excavated to a depth of 10 inches below the surface of the intended pavement, and as much farther as may be necessary to obtain a solid foundation and remove all objectionable material, the space being filled to the proper level with clean sand, gravel, or other suitable material. On this foundation, is placed a layer of fine, clean, sandy gravel, containing no pebbles larger than $1\frac{1}{2}$ inches in greatest dimension, the gravel having a depth of not less than 4 inches when consolidated. After this layer has been thoroughly consolidated by rolling or ramming, a layer of fine, clean, sharp sand, 4 inches in thickness, is spread on it to serve as a bed for the bricks. The surface of this sand bed is made parallel to the intended surface of the finished pavement and brought to a depth below it equal to a little less than the thickness of a brick.

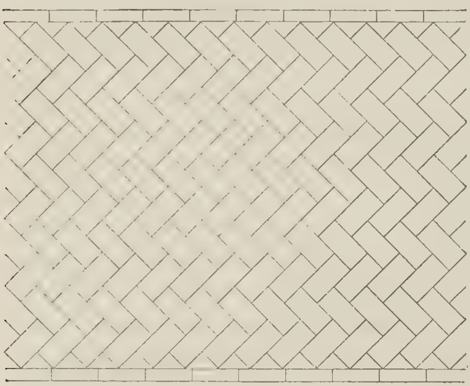


Fig. 23

The bricks are laid flat on this bed of sand, either at right angles to the line of the footway, or diagonally in the manner known as the herring-bone style, the bricks being of uniform width and depth and so laid as to break joints longitudinally by a lap of not less than 2 inches. In laying the bricks, the pavers stand or kneel on the bricks already laid, so as not to

disturb the bed of sand. When thus laid, the bricks are immediately covered with fine, clean, sharp sand, free from clay, loam, or earthy matter; they are then carefully rammed by striking with a heavy hammer on a plank placed over several courses. The ramming is continued until the bricks are settled to a solid, unyielding bed. When the ramming is completed, fine dry sand is spread over the surface and swept into the joints. The plan of a portion of a brick footway laid in this manner is shown in Fig. 23. It will be noticed that when the bricks are laid in this way, special triangular-shaped bricks are required to fit against the curbing at the sides of the footway, which is formed by bricks set on edge. Usually these triangular bricks are cut from whole brick by the paver.

95. Asphaltic-Mastic Sidewalks.—Sidewalks of asphaltic mastic are constructed in France in the following manner: A mastic is prepared from a combination of natural rock asphalt and a refined asphalt fluxed with an asphaltic oil, and laid to a thickness of about 1 inch on a cement-concrete base about 4 inches thick, the top of which has been treated with a layer of cement mortar $\frac{1}{2}$ inch to 1 inch thick. Gravel is spread over the surface and lightly rolled into the asphaltic mastic while the latter is still warm.

96. Sheet-Asphalt Sidewalks.—Sheet asphalt makes an excellent sidewalk; it is durable, agreeable to walk on, and does not wear slippery. The asphalt is used both in the form of sheet asphalt and in the form of compressed tiles.

Sheet-asphalt walks are constructed in about the same manner as the sheet-asphalt pavements for roadways, except that the construction is of a lighter character. The ground should be excavated to a depth of 3 inches below the intended surface of the pavement, and to a greater depth where necessary in order to remove unsuitable material and to secure a firm foundation, the deficiency being filled with clean gravel or other proper material; this foundation should be thoroughly rolled or rammed. On the foundation thus formed should be spread a layer of clean broken stone, to such depth that, after compacting, it will have a thickness of 2 inches. When

this has been compressed by rolling and tamping, a bituminous cement should be poured over it, about $\frac{1}{2}$ gallon being used to each square yard of pavement. This material should be poured on the broken stone in such a manner as to thoroughly coat the stones and fill the interstices.

The wearing surface should consist of a sheet-asphalt paving mixture spread on the base by means of hot iron rakes to such depths as will give a thickness of 1 inch after compression. It should then be thoroughly compressed by rolling,

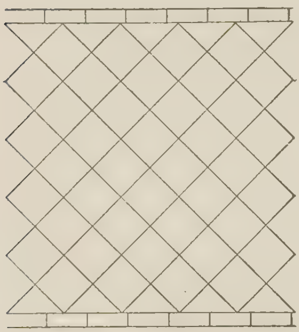


Fig. 24

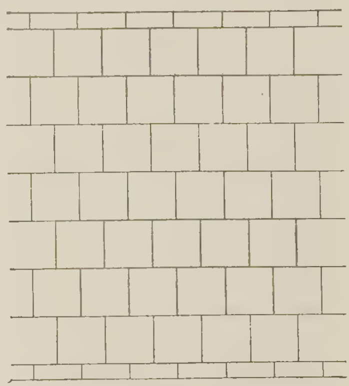


Fig. 25

during which process a small amount of hydraulic cement should be swept lightly over the surface.

97. Compressed-Asphalt Tile Walks.—The compressed-asphalt tiles used for walks are formed in nearly the same manner as the asphalt paving blocks; the tiles, however, are usually 8 inches square and 2 to $2\frac{1}{2}$ inches thick, or of hexagonal form $5\frac{1}{4}$ to 8 inches on the short diameter. The construction of these walks is almost identical with the construction of brick footways. Two methods of laying the tiles are shown in Figs. 24 and 25.

98. Wood Sidewalks.—Wood in the form of planks has been extensively used for sidewalks. This material makes footways that are cheap in first cost, and when in good condition are pleasant to walk on. They soon get in bad condition,

however, and not only require constant attention and repairs, but also become unpleasant and even dangerous for pedestrians.

Wood walks are commonly constructed of pine plank 2 inches in thickness and surfaced on the upper side, laid crosswise of the walk on wooden stringers 4 in.×4 in. in cross-section; the stringers are laid longitudinally and bedded in the earth.

99. Walks of Tar Concrete.—Tar concrete has been extensively used for walks in several cities. In general, the walk is constructed in two courses: a wearing course about 1 inch thick consisting of tar mixed with coarse sand, and a 4-inch foundation of coarse gravel well coated with tar. This kind of walk soon becomes worn and quickly deteriorates. It should, therefore, be considered only as a temporary substitute for a walk of a more permanent character.

100. Gravel Walks.—Gravel makes an excellent sidewalk pavement for suburban districts, parks, and pleasure grounds. If properly constructed and well drained, such pavement forms, in the proper localities, a pleasant and durable footway.

The same principles apply to the construction of gravel walks as to the construction of gravel roads, the chief requirements being that they must be thoroughly drained and well compacted by rolling. The greatest agency of destruction affecting gravel walks is storm water flowing over the walks, washing out gulleys, and otherwise damaging them; hence, it is essential that in their construction water from adjoining slopes be kept off them as much as possible, and that adequate drainage be provided to remove quickly whatever water may reach them.

GUTTERS AND CURBS

GUTTERS

101. Purpose of Gutters.—As a general rule, paved gutters are not constructed along the sides of roads, except on grades where there is danger of wash-outs. However,

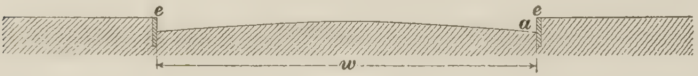


FIG. 26

along each side of a street roadway some kind of open channel must be provided to receive the water from the surface and convey it to a drainage outlet. Deep side ditches, such as are used on country roads, would be unsightly, dangerous, and otherwise impracticable for a city. Surface drainage in city streets is accomplished by forming those parts of the roadway adjacent to each outer edge to serve as gutters for conveying

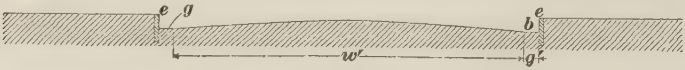


FIG. 27

the water from the surface. These gutters are made so shallow as to be available, to some extent, for driving purposes when not required for drainage.

102. Construction of Gutters.—Various forms of gutter are used; of these, the three shown in Figs. 26, 27, and 28 are the most common. The form shown in Fig. 26 is the simplest and, all things considered, probably the most advantageous for well-paved roadways. It is very commonly used

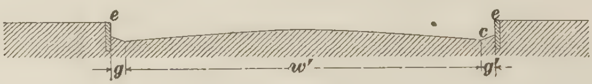


FIG. 28

with the best pavements. In this form, the crown of the roadway is continued regularly to the curb line, the gutter

being formed at a by the angle between the sloping surface of the roadway and the vertical side of the curbing. The full width of the roadway is thus left available and convenient for driving. The form of roadway shown in Fig. 27 is the same as that shown in Fig. 26, except that the bottom g of the gutter b is made level. Little, if any, advantage is gained, however, by this method and this form of gutter is not in general so good, nor nearly so extensively used, as the form shown in Fig. 26. Where the gutters are paved with cobblestone, the form shown at c in Fig. 28 is very commonly employed. When a substantial stone curbing is used, it is doubtful whether any advantage is gained by this form of gutter, while it possesses the disadvantage of narrowing the available driveway w', and also of making it inconvenient to drive close to the curbing.

103. Gutters are constructed of brick, stone block, cobblestone, and cement concrete. Cobblestone is extensively used in constructing gutters on roads. Cobblestone, cement-concrete, and brick gutters are frequently built adjacent to broken stone surfaces on streets. Brick gutters are also very popular in some cities where sheet-asphalt and bituminous-concrete pavements are built.

Although stone-block, cobblestone, cement-concrete, and brick gutters are usually constructed with the same transverse slope as the adjoining surface of the roadway of a street, it is better in the case of highways to increase the water-carrying capacity of the gutters either by building them on a sharper slope or by building them with a concave-curve section. The depth of the gutter at the center of this curve varies from 4 to 9 inches, depending upon the width and grade of the gutter. The gutters are built from 2 to 6 feet in width, depending upon the amount of water to be carried, 3 or 4 feet being widths used under ordinary conditions. Cobblestone, cement-concrete, and brick gutters are commonly constructed on a foundation of sand, gravel, or cinders, the joints being filled with sand or poured with a cement grout.

CURBS AND CROSSWALKS

104. Curbs in General.—Flat stones are usually set on edge along the borders of the roadway, as shown at *e* in Figs. 26, 27, and 28; these stones are called curbs, or curbing. They are usually set vertically on edge, but are sometimes set somewhat sloping. In some cases, earth or gravel roadways have gutters paved with cobblestone, as shown in Fig. 29, no curbs being set. The top of the curbing is usually set to the grade line adopted for the street, or at the same elevation as the center or crown of the street.

105. Materials for Curbing.—The materials most commonly employed for curbstones are natural stones, such as granite, sandstones, etc., dressed to suitable form; in some cases cement concrete is used. In a few cases fireclay, cast iron, and wood have been employed. Natural stone is the material generally used in localities where obtainable; in localities where natural stone is not obtainable, cement concrete is

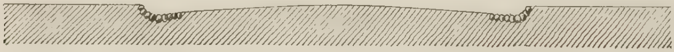


FIG. 29

probably the best material. Granite is generally considered the best material for curbs, although sandstone and limestone are both used.

106. Form and Dimensions of Curbstones.—The form and dimensions of curbstones vary considerably in different localities, and, being largely matters of appearance only, are not subject to rigid requirements of construction. Curbstones vary from 4 to 12 inches in width, from 8 to 24 inches in depth, and from 3 to 6 feet in length, according to the requirements of specifications, depth of gutter, etc. The depth of a curbstone should always be sufficient to prevent the stone from turning over or tipping toward the gutter; this condition will depend somewhat on the width of the stone; the length should not be less than 3 feet.

The front face of the curbstone should be hammer-dressed to a depth somewhat greater than that exposed above the gut-

ter; where the sidewalk joins the curbing, the back of the curbstones should be dressed to a sufficient depth to allow the sidewalk pavement to fit closely against it. The ends of the curbstones should be dressed throughout their exposed depth, and the portion below the gutter surface should be so trimmed off as to permit them to be laid with close joints. The top surface of the curbstones should be dressed to a bevel corresponding to the slope of the adjoining sidewalk. The bed of the curb should generally be not less than 6 inches in width. Cement-concrete curbstones are sometimes made hollow, in order to provide conduits for electric wires, pipes, etc.

107. Stone Curbing.—Great care should be exercised in setting the curbing. It should be set true to line and grade,

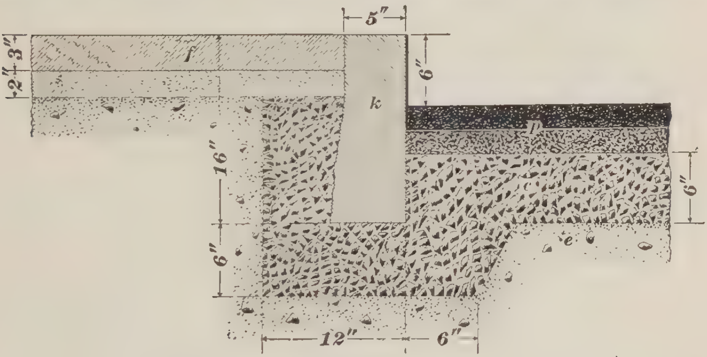


FIG. 30

and the curb should always be bedded firmly on a solid foundation. The work should be thoroughly and substantially done, so that the curbing will keep its proper position, and not sink nor tip toward the gutter.

Curbing is set in various ways: It is either set directly on the earth foundation, on a gravel foundation, or on a concrete foundation; the last-mentioned method is by far the best. The foundation of the curb should be made continuous with the foundation of the roadway. A curb set in concrete is shown in Fig. 30; *e* is the natural earth; *c*, the concrete foundation; *p*, the wearing surface of the roadway pavement; *k*, the curbstone; and *f*, the sidewalk flagging. The common dimen-

sions of the different parts are marked on the figure. The dimensions of the wearing surfaces of roadway pavements are not given, because they are of different thicknesses according to the material used.

108. Concrete Curbs.—A simple form of concrete curb is shown in Fig. 31. This curb is usually built in wooden molds, as shown, which are removed after the concrete has set. The concrete should not be poorer than 1 part Portland cement,

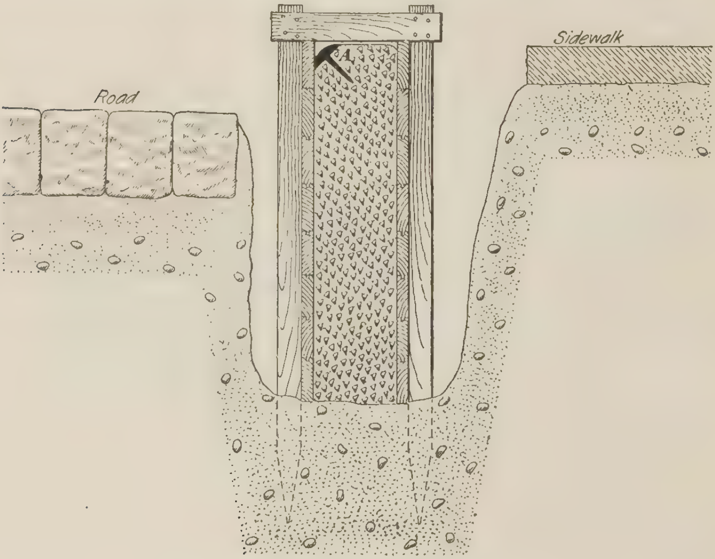


Fig. 31

2 parts sand, and 5 parts broken stone. The stone should be hard and durable, and the concrete wall should be spaded against the sides of the molds to insure a smooth surface. The top should be troweled smooth.

This form of curb is divided into certain definite lengths of from 6 to 10 feet, by breaking its continuity with sheets of tar paper or the like. These joints insure that all cracks due to shrinkage will be vertical and at definite points. As shown at *A*, Fig. 31, a steel guard is sometimes put on the curb to protect the concrete when wagons are backed up against it.

This form of curb may be set on a wide concrete base, the same as a stone curb.

109. Combined Concrete Curb and Gutter.—A concrete curb and concrete gutter are sometimes constructed in one piece, as shown in cross-section in Fig. 32, where the curb a and the gutter b are combined and the whole structure rests on a layer of gravel or cinders. In this case the depth of the curb is somewhat less than the simple curb shown in Fig. 31, and is therefore less stable than the latter. Both types of construction, however, are suitable for roads where there is no concrete foundation under the pavement.

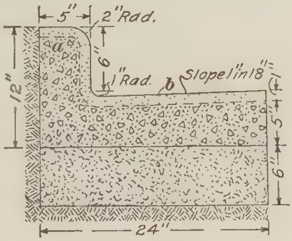


FIG. 32

110. Integral Curb.—When a street is to be curbed and paved at the same time, and the pavement is to have a concrete foundation, the curb and foundation may be made monolithic, or integral, as shown in Fig. 33, where a is the concrete foundation; c, the concrete curb; b, the brick wearing surface of the street pavement, and d, the sand cushion. Two outlines of curb are indicated. The full line e shows the better design, since the sloping face provided is less likely to be injured by rims and tires of vehicles than is the vertical face f, shown dotted.

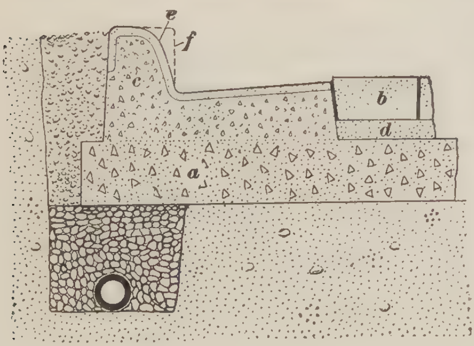


FIG. 33

111. Cross-walks.—At street intersections, or wherever the footway of one street crosses the roadway of another street, it has been customary, in order to make the footway continuous, to lay two or more rows of stone slabs across the roadway. For the convenience of pedes-

trians, these have been laid as nearly at the grade of the footway as circumstances permitted. Such stones are called crossing stones or bridge stones. They have been generally laid at the street intersections in stone pavements, but are commonly omitted from the smoother pavements, such as asphalt and brick. With the introduction of the improved stone-block pavement, the use of crosswalks is rapidly disappearing.

CULVERTS, CAR TRACKS, AND GUARD-RAILS

CULVERTS AND PIPE SYSTEMS

CLASSIFICATION AND GENERAL DESIGN OF CULVERTS

112. Culverts in General—Culverts are arched, flat, or circular openings lined with timber, iron, brick, or masonry,

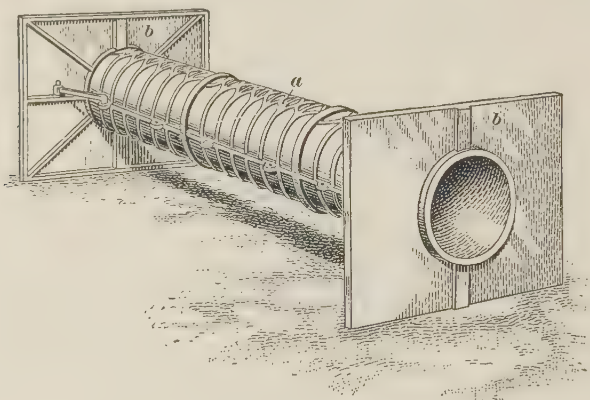


Fig. 34

and serving the purpose of providing a passage for water under highways and railroads.

Culverts are commonly classified as *pipe, box,* and *arch* culverts. Pipe culverts are constructed of vitrified clay, cast iron, corrugated metal, plain or reinforced concrete, brick, and

timber. Box culverts are built of stone, plain or reinforced concrete, and wood. Arch culverts are constructed of stone, plain or reinforced concrete, and brick.

113. A cast-iron pipe culvert is shown in Fig. 34, in which *a* is the pipe, made up of several sections, and *b* the end plates which serve as head walls. Fig. 35 shows a pipe culvert which consists of several sections of precast reinforced-concrete pipes *a*. At each end of the culvert the pipes pass through the head walls *b*, provided with the wing walls *d*, both resting on footings *c*. The head walls and wing walls serve the purpose of retaining the earth of the embankment and preventing erosion of the bank. The wing walls are

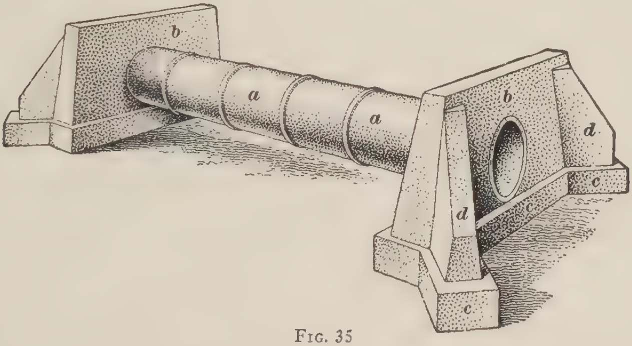


FIG. 35

usually placed at an angle in order to contract the stream from its natural width to the narrow passage of the culvert.

114. In Fig. 36 is shown a reinforced-concrete box culvert with an opening 3 feet high by 5 feet wide. The material to be used for the floor will depend on the soil. For a firm soil, paving stones may be employed, but for a relatively soft soil the floor is usually made of plain or reinforced concrete. In (*a*) is shown a plan view of the culvert in the left half of which part of the top is removed to show the footing course on the inside of the culvert; in (*b*) is shown a half cross-section of the culvert to the left of the center line, and a half front elevation to the right of the center line, while in (*c*) is shown a section on the line *A–A*, through the head wall.

Fig. 37 shows an example of an arch culvert: (*a*) is an end elevation, (*b*) is a side elevation of the head wall, and (*c*) is a typical cross-section through the culvert.

115. Selection of Culverts.—The selection of the type of culvert and the material to be used is largely a question of economy, particularly in the case of small waterways. The availability of labor and materials, the first cost of the culvert,

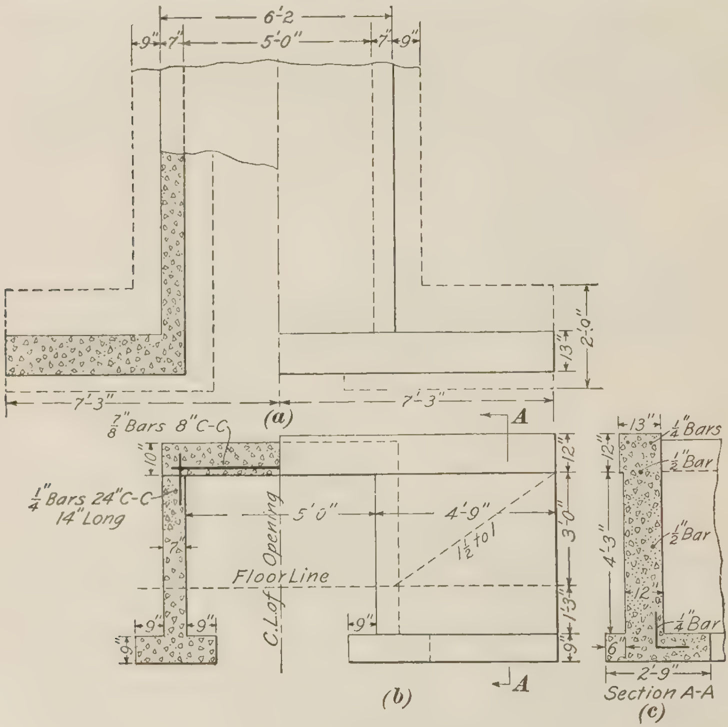
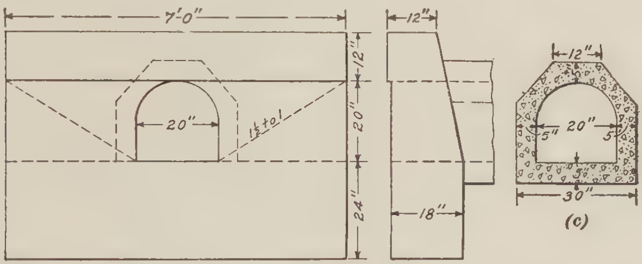


Fig. 36

freight charges, cost of hauling, and cost of construction have to be considered. There may be cases where considerations other than cost would determine the selection of the type, such as, for example, the depth of fill over the culvert. Some kinds of pipe are not manufactured in diameters over 3 feet. When large areas of waterways are required, it will be necessary to use either a culvert of the box or arch type or two or more

lines of pipe, the selection being based on the relative economy and durability of each method.

116. Design of Culverts.—Culverts are required to support both the weight of the material that covers them, and the superimposed loads. In addition, they may be subjected to severe expansive forces caused by water freezing within them. The amount of load carried by the culvert cannot be accurately determined, on account of the unknown action of earth pressure and of the distribution of superimposed loads. The load reaching the culvert will, therefore, have to be assumed. In using standard pipes of cast iron, corrugated metal, or vitrified clay, it is ordinarily not necessary to investigate their strength, since they have been used under suffi-



(a) FIG. 37 (b)

ciently varying conditions to demonstrate that they will resist successfully any load that they are likely to receive, provided the pipes are properly placed. The designs of reinforced-concrete and concrete pipes, and of box and arch culverts should be carefully made so that proper support will be furnished for the loads that must be carried.

117. Location of Culverts.—The proper location for a culvert can only be determined by an examination of conditions in the field. It is true that some idea as to the need of a culvert may be gained from looking over the profile of a highway on the drawing, since culverts are usually needed at all low points of the grade. When these places are examined in the field, however, it may be found that the ground slopes away from the road on both sides and hence, in some

cases, no culverts will be needed to carry the water across the road. Other places, not apparent on the plans, may be found by a field examination, where water will form a pond and cause property damages unless a culvert is constructed to remove it. In cuts with shallow side ditches, in localities where the highways are curbed, and in any place where it is not possible to obtain sufficient cover over the culvert and still have the inlet end of the culvert above the surface of the ground, some form of catch basin or drop inlet, to be described later, will have to be built.

Small culverts of the pipe or box type and small arch culverts are usually constructed at right angles to the axis of the road. However, when used on hills to carry the water from one side of the road to the other, the culvert is laid more nearly in the direction of the flow, so that its angle with the axis of the road will be smaller than a right angle. This scheme is also used in some cases to obtain sufficient cover over the culvert, or to bring the point of outlet to a more convenient place.

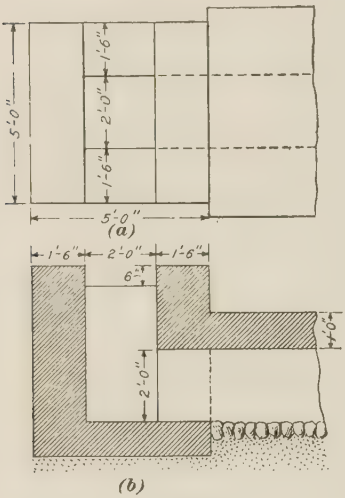


FIG. 38

CONSTRUCTION OF CULVERTS, INLETS, AND CATCH BASINS

118. Foundation, Head Wall, and Pipe.—Culverts of all types should be built on a stable foundation. If the soil furnishes a poor support, the pipes should be bedded in a layer of concrete or broken stone. A head wall should generally be constructed on both ends of a pipe culvert. The use of head walls makes it possible to employ a somewhat shorter culvert than would otherwise be necessary. Head walls for small culverts are usually built parallel to the center line of the road. Sometimes, however, it may be found advis-

able or more economical, in the case of culverts of large size, to construct wing walls, either straight or flared, as at *d* in Fig. 35. Concrete and stone masonry are used in building head walls. Cheapness, durability, and the fact that concrete can be molded into any form desired, renders it a very satisfactory material for this purpose. The bottom of the head wall should be carried 18 inches or more below the bottom of the pipe to prevent washing out.

119. Drop Inlets and Catch Basins.—Frequently the inlet end of a culvert will have to be placed at a level below the bottom of the ditches leading to it. Where this distance is not great, it is possible to construct a drop inlet, which is an open box of concrete or stone masonry. A drop inlet of this type is shown in Fig. 38, where (*a*) is a plan and (*b*) a vertical longitudinal section. Unless the inlet is far enough removed from the traveled way so as not to be dangerous to traffic, a grating over the top is necessary.

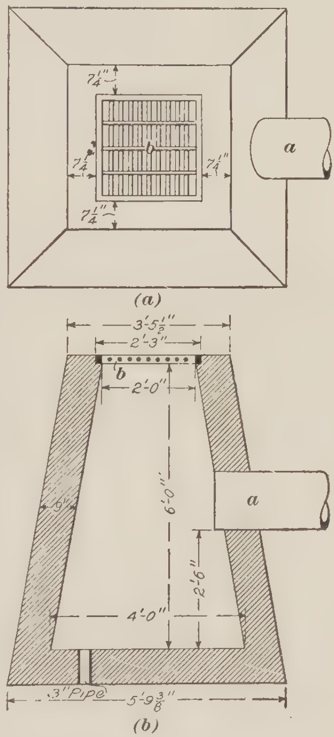


FIG. 39

120. In places where the wash carried along by the water is of large amount, a catch basin is more serviceable than a drop inlet, as there is not so much danger of the pipes becoming choked. The size of the catch basin will depend on just how much material is liable to be washed into it and how often it is to be cleaned out. The bottom of the catch basin is usually placed 1 to 3 feet below the bottom of the pipe so as to provide a sump to hold back dirt and debris from entering the culvert pipe. The inlet should offer as little obstruction as

possible to the water, and the grating should be of such a form as not to be dangerous to traffic. In Fig. 39 (*a*) is shown a plan of a concrete catch basin, and a sectional elevation is shown in (*b*). In this example, the culvert pipe *a* is 2 feet 6 inches above the bottom of the basin. The top opening is 2 feet square and is covered by the grating *b*. If the inlet is so placed that the traffic will pass over it, the casting covering it must be strongly made. An inlet casting is shown in Fig. 40, *a* being the grating and *b* a continuation of the curb.

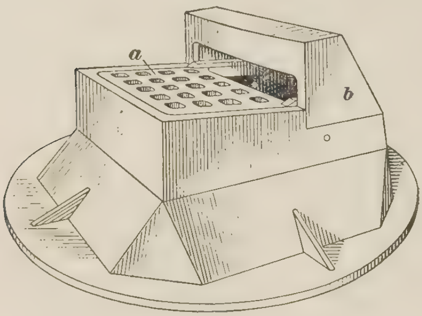


Fig. 40

PIPE SYSTEMS

121. General Arrangement.—Pipes for sewage, water, and gas are an essential part of the development of any built-up district, and in designing the streets due allowance must be made for the accommodation of such systems. These systems are not all built at the same time. The water-supply and sewerage systems are generally installed by the municipality, the custom being to build and extend these systems as the growth of the locality demands. The gas pipes, and conduits for telephone, telegraph, or electric-light wires may be laid by many different corporations and at various times. In a great many cities, extremely poor records of the location of their services have been kept by these private corporations. With all of these various systems underneath the surface of the street it is not surprising that the streets are continually torn up. This condition of affairs can be improved only by proper administration and legislation.

Many of the services mentioned have connections running to the houses that face on the street, and therefore must be placed somewhere between the property lines, in the space

generally divided into two sidewalks and one or more roadways. In some cases a narrow parking space is left between the curb of the walk and the paved sidewalk; this plan, however, will generally be found only in the residential parts of a city. Unless the sidewalks or parking spaces are very wide, it is necessary to locate some of the pipe systems in the roadway.

122. Approved Method of Placing Pipes.—It is rarely feasible to have a roadway of a street without any pipe systems beneath it. The principle to be kept in mind is to place beneath the roadway those systems that will be disturbed the least. They should be located in such a manner that repair work, if necessary, may be accomplished with a minimum disturbance of traffic. If all of the different systems can be laid in a street before the roadway is surfaced, and if the house connections can be extended to the property lines at the same time the installation of the different systems is made, such a procedure will prevent, to a large extent, disturbance to the roadway at later periods. In some cities, no disturbance to the roadway is permitted within a certain number of years after it is surfaced, and before the roadway is surfaced notice is given to property owners to make all necessary pipe extensions.

CAR TRACKS AND GUARD-RAILS

CAR TRACKS

123. Location of Car Tracks.—There are several advantages in having the car tracks located on a part of the highway that is inaccessible to other traffic. This arrangement does not interfere with the convenience of those entering and leaving the cars and has the added advantage that the cars can be operated at higher speeds without danger to other traffic. The work incident to the maintenance of the tracks can be carried on without disturbing the surfacing of the roadway, and, obviously, since the tracks are outside the road-

way, the wear of the latter is not affected by their presence. This arrangement may be used in cases of wide residential streets or boulevards, where the tracks may be located either at the sides or in the center of the highway. The usual practice is to have the car tracks located within the roadway, either in the center or at the sides, the tracks being made flush with the adjoining pavement so as to offer as little obstruction as possible to other vehicular traffic. Whether the tracks should be located in the center or at the sides is dependent upon local conditions, but primarily depends upon the width of the roadway.

124. Foundations for Tracks.—Experience has shown that the maintenance of a roadway surface adjacent to a car track is usually more costly than that of other portions of

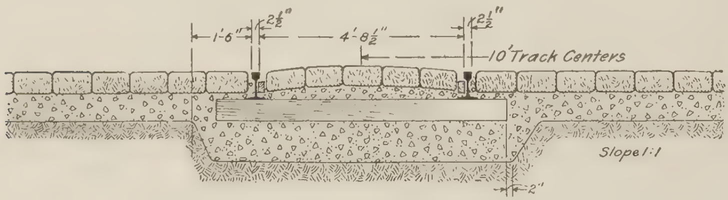


FIG. 41

the surface. Water that seeps down by the rail, particularly at the joints, softens the underlying soil, with the result that the track moves up and down and the adjacent pavement is soon disintegrated. It is very important, therefore, that the track should be thoroughly drained.

The simplest form of track foundation is made by embedding wooden ties in gravel or broken stone. This method is ordinarily used for tracks constructed on roads surfaced with broken stone or similar material, and for tracks that are built on a right of way that is inaccessible to other traffic. When the track is flush with the roadway and adjacent to pavements of wood block, granite block, brick, or any form of bituminous pavement, it is essential that a cement-concrete foundation be provided that will make the track as rigid as possible. When wooden ties are used they are generally creosoted before being

laid, as the creosoting increases their life considerably. Some car companies use steel ties; others lay the rails directly on the concrete, or on concrete stringers.

125. Rails.—The rails generally used for car tracks are the **T** rail, shown in Fig. 41, and the grooved rail, shown in Figs. 42 and 43. Car companies generally prefer the **T** rail because it lends itself to cheaper construction and is less likely to become clogged with dirt or snow. On earth or macadam highways the **T** rail offers no more trouble in maintenance of the road than the grooved rail. The disadvantage of the **T** rail on paved highways is that it offers no grooves for the flanges of the car wheels, and hence makes it necessary to leave a groove between the pavement and the rail on the inside of the track, as shown in Fig. 41, which is a source of weak-

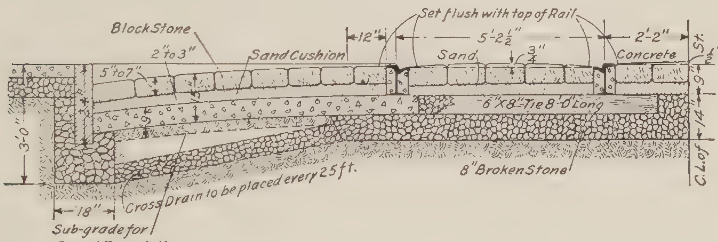


FIG. 42

ness in the pavement. Another method is to depress the pavement under the flanges of the wheels, but that is objectionable because it tends to hold the wheels of vehicles in the track and makes it inconvenient for vehicles to cross the track, due to the drop from the rail to the pavement. Many city authorities, therefore, insist on the use of the grooved rail, shown in Figs. 42 and 43, which, although more objectionable from the point of view of the car companies, is more desirable for maintenance of the pavement. It permits making the pavement flush with the top of the rail, leaves no ruts between the pavement and the rail, and offers little obstruction to vehicular traffic.

126. Surfacing Adjacent to Rails.—If the rails are of sufficient depth to provide room for blocks and a firm

foundation over the ties, brick, wood, and stone-block pavements can be constructed up to and between the rails in the manner shown in the cross-section, Fig. 42, where stone-block paving is employed. Although bituminous pavements have been constructed up to and between the rails, better results have been obtained when some form of block has been placed between the edge of the pavement and the rail, as shown in

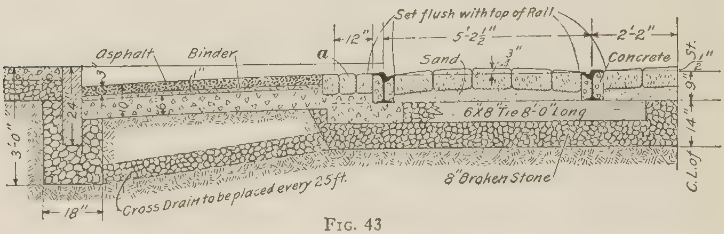


FIG. 43

Fig. 43, where a course of blocks is placed at *a* between the asphalt pavement and the rail. In cases where the rails are so shallow that blocks cannot be laid on edge between them and the pavement, an 18-inch strip of water-bound gravel or broken stone has been found to work satisfactorily. Paving blocks, laid flat, and cobblestones have also been used with good results.

GUARD-RAILS

127. Position and Material.—Guard-rails should be placed at the tops of all embankments and at culvert ends where there is the slightest element of danger. Wood, iron, and concrete are the materials used in the construction of guard-rails. Guard-rails are placed 12 inches from the edges of the embankment toward the center of the road; on concrete or masonry head walls they are generally placed in the center of the masonry.

128. Construction.—The posts of wooden guard-rails are made of cedar, white oak, or chestnut, 6 inches in diameter. The length varies from 6 to 7 feet, of which length about 3 feet 6 inches is above ground. The top rail, which is 4 inches square, is fish-tooled into the tops of the posts; that is, it rests

in notches in the tops of the posts in such a position that one of the diagonals of the cross-section of the rail is horizontal. The distance between posts is generally 8 feet and the rails are 16 feet long.

Iron-pipe railing is used across culverts and at places where the roadway is retained by masonry walls. The posts are generally of 2-inch pipe and the rails of $1\frac{1}{2}$-inch pipe, there being three rails spaced 13 inches apart, center to center. The posts are not to be farther apart than 8 feet and are set 10 to 12 inches deep in masonry.

129. Where timber is expensive, or is not suitable by reason of its inflammability, fences may be built wholly of concrete or the posts may be of concrete and carry wire strands strung between them. Concrete posts are about 7 feet long and 5 and 6 inches square at top and bottom, respectively, and are set 3 feet 6 inches in the ground. Concrete guard-rails are of rectangular trough section provided at certain intervals with cross diaphragms connecting the sides and the top.

APPENDIX TO HIGHWAYS

ECONOMICS OF HIGHWAY ENGINEERING

INTRODUCTION

1. Benefits of Improved Highways.—The construction and maintenance of highways involve the expenditure of large sums of money which must eventually be paid by the people. In business, unless the capital invested is protected by available assets and unless it has an earning capacity, the investment is not considered a desirable one. It is impracticable to state the value of good roads in dollars, although statisticians have frequently attempted to show the saving that would result in the cost of hauling various products over improved surfaces. Such figures may be very misleading, since they are based frequently on data of a meager nature. The return for the capital invested will therefore have to be summed up from the standpoint of the advantages resulting from the improvement of highways. The benefits that result from the construction of a given highway naturally depend upon its local environment.

In the following list, the advantages and benefits of good highways are set forth, but with no attempt to place them in the order of their value, since the value of each will vary with the individual highway. The advantages are: (1) Development of commerce; (2) development of industries; (3) devel-

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opment of agriculture; (4) development of natural resources; (5) development of intellectual and social life; (6) improved appearance of roads and streets; (7) permanency of alinement and grade of highways; (8) decrease in cost of transportation; (9) development of methods of transportation; (10) facilitation of travel; (11) development of tourist travel; (12) improvement of sanitary conditions; (13) increase in land values; (14) increase in fire protection; (15) increase in rural population; (16) development of rural free delivery.

It is evident that, in general, only several of the benefits mentioned will result from the improvement of any specific highway.

2. Improved highways outside of urban districts promote the development of agricultural, commercial, and manufacturing industries, by reason of the facilities they offer for intercourse at all seasons of the year, and because they afford opportunities for selecting the most advantageous time and place for marketing crops. Good roads also aid in improving the social and intellectual condition of the rural population, by facilitating intercourse between it and the urban populations.

3. Necessity for Pavements.—Pavements are constructed for the purpose of improving the facilities for, and reducing the cost of, transportation, and for increasing the safety, speed, and comfort of travel. The duty of a pavement is to furnish an impervious covering that will protect the soil of the natural foundation and distribute the concentrated weight of the loads more evenly on it, at the same time affording a smooth even surface that will offer the least possible resistance to traction, and over which vehicles may pass with ease and safety.

FINANCING OF HIGHWAY IMPROVEMENTS

4. Systems of Financing.—The systems of financing the construction and maintenance of highways in the United States will be considered under the following headings: (1) Labor tax; (2) convict labor; (3) direct taxation;

(4) direct appropriation; (5) bond issues; (6) private subscriptions.

5. Labor-Tax System.—The labor-tax system permits the payment of highway taxes in labor instead of cash. Until 1890, this system was extensively used in the United States in the development of highways outside of municipalities. Little good can be expected from such a system, since interest and earnestness of effort are generally lacking. The work is usually done at times that suit the convenience of those that perform it, rather than at times that are most advantageous for the improvement of the highways. Of course, work done by this method is generally better than none at all, but usually the expenditure of a sum of money equivalent to the amount allowed for the labor will, under intelligent administration, produce much better results. There are instances, however, where results accomplished by this method have been very satisfactory, as, for example, the excellent work done with road drags on the highways in different parts of the country, particularly in connection with the maintenance of earth roads.

6. Convict-Labor System.—Since 1910 the utilization of the labor of convicts has received considerable attention in many parts of the United States. The following conclusions have been derived from an exhaustive study of the use of convict labor on highways by various authorities: (1) The successful use of convict labor on highway work does not depend upon climatic conditions, geographical location, or class of prisoners; (2) the honor system should be employed and commutation of sentence allowed; (3) a wage should be paid, which, however, should not exceed the actual earnings of the prisoner; (4) all highway work should be under the direction of engineers of the highway department, but the control, housing, clothing, and feeding of the prisoners should be under the supervision of prison representatives; (5) quarry work, brick making, grading and drainage work, and the construction of cement-concrete structures are types of highway work particularly well adapted for the utilization of convict labor in connection therewith.

7. Direct-Taxation System.—In many communities a certain part of the general tax is assessed as a highway tax to be used for the construction and maintenance of the highways. It is generally, however, of such small amount in rural districts that very little new construction can be accomplished. In order to further the construction of new highways, several states levy a tax for this purpose on the abutting property, which pays in part for the cost of new construction. Such a system is thought to be an equitable one in some localities. In districts where there are large areas between the highways, the amount of tax is varied, depending upon the distance of the property from the highway. One advantage of the direct tax is that future indebtedness is obviated.

The cost of highway work in many of the cities of the United States is defrayed by some form of special assessment. While in some cases the entire cost of grading is paid by the city, there are a few instances where the city pays a certain percentage of this cost. The same general scheme is also carried out in the original construction of pavements and in repaving work. The amount of assessment is based on the frontage of the property on the street, on the total area, or on a combination of the frontage and the area. The frontage rule is more commonly used than either of the others. In some cases the amount assessed is due on completion of the work. In others, however, the amount is paid in several equal annual instalments, deferred payments bearing interest.

Another form of direct taxation is the licensing of motor vehicles. The money received in license fees for both vehicles and operators and the money received from penalties and fines imposed for non-observance of the laws are usually paid into the state treasuries to be used for the maintenance of highways.

8. Direct-Appropriation System.—When payment for highway improvement is made from the general taxes of a community, the expense is borne by all the people residing therein. A large amount of the state highway work is paid for on this basis. In many municipalities and towns an amount

sufficient to cover the cost of the highway improvement is made an item of the annual budget.

9. Bond-Issue System.—Because of the large sums of money required where extensive construction is contemplated, the revenue available from the general taxes will not usually meet the expense of the improvement. In such cases it has become common procedure to issue bonds, bearing interest of from $2\frac{1}{2}$ to 6 per cent., which are redeemable at different periods. The yearly cost of the bonds will be the sum of the amount that will have to be paid out in interest and the amount which will have to be set aside as a sinking fund to redeem the bonds. The issuance of bonds renders a large sum of money available for immediate use and extends the repayment over a long period of years. However, if the term of the bonds is made so long that the highways are worn out before the bonds are redeemed and no provision is made either for the maintenance of the highways or for the redemption of the bonds, a very unfortunate financial situation arises. Careful provision should therefore be made to avoid such a situation.

10. Private-Subscription System.—There are a few instances where highways have been built by private subscription. The largest undertaking of this kind is the Coleman du Pont Road in Delaware. There have been several roads constructed throughout the country, however, by private capital as a business enterprise. These roads after construction were operated as toll roads, but most of them have been taken over by the states through which they pass and have been converted into public highways.

ORGANIZATION AND ADMINISTRATION OF HIGHWAY DEPARTMENTS

11. Scope of Work of Highway Departments.—A highway department should be vested with the following powers: (1) Control of the construction and maintenance of the highways within the territory under its jurisdiction; (2) charge of all surveys, mapping, and design connected

with highways and bridges constructed or maintained by the department, and the testing of all materials used in the work of the department; (3) supervision of the superstructures and substructures of electric and steam railroad companies, telegraph companies, telephone companies, waterworks companies, and all other public utilities companies, so far as the control and maintenance of their structures within the limits of highways are concerned; (4) power to formulate and enforce the traffic regulations covering the operation of motor busses, motor trucks, other types of motor cars, and all types of horse-drawn vehicles on the public highways; (5) control of cleaning of roadways and of snow removal, and, in the case of urban districts, the collection and disposal of ashes, rubbish, and garbage.

12. Fundamentals of Organization of Highway Departments.—In order to attain efficiency in all departments of work to be carried out under the jurisdiction of a highway department, it is necessary that the duties assigned to the department, and the personnel and interrelationship of the several units of the organization, should be based upon the following fundamental principles: (1) A highway department should have control of all branches of work relating to the substructure and the superstructure of highways within the limits of the right of way; (2) inspectors and all engineers having charge of surveys, mapping, design, construction, and maintenance should possess a degree of engineering training, education, and experience dependent upon the responsibility of the positions that they occupy; (3) the personnel and the work of the organization should not be affected by political influence or, from a technical standpoint, by the dictation or influence of a layman or bodies of laymen; (4) the interrelationship of the several units of a highway department should be based upon the principles governing the organization of an army—that is, there should be a continuation of authority from the most minor executive to the administrative, executive, and engineering head of the organization; (5) all positions in a highway department should be filled

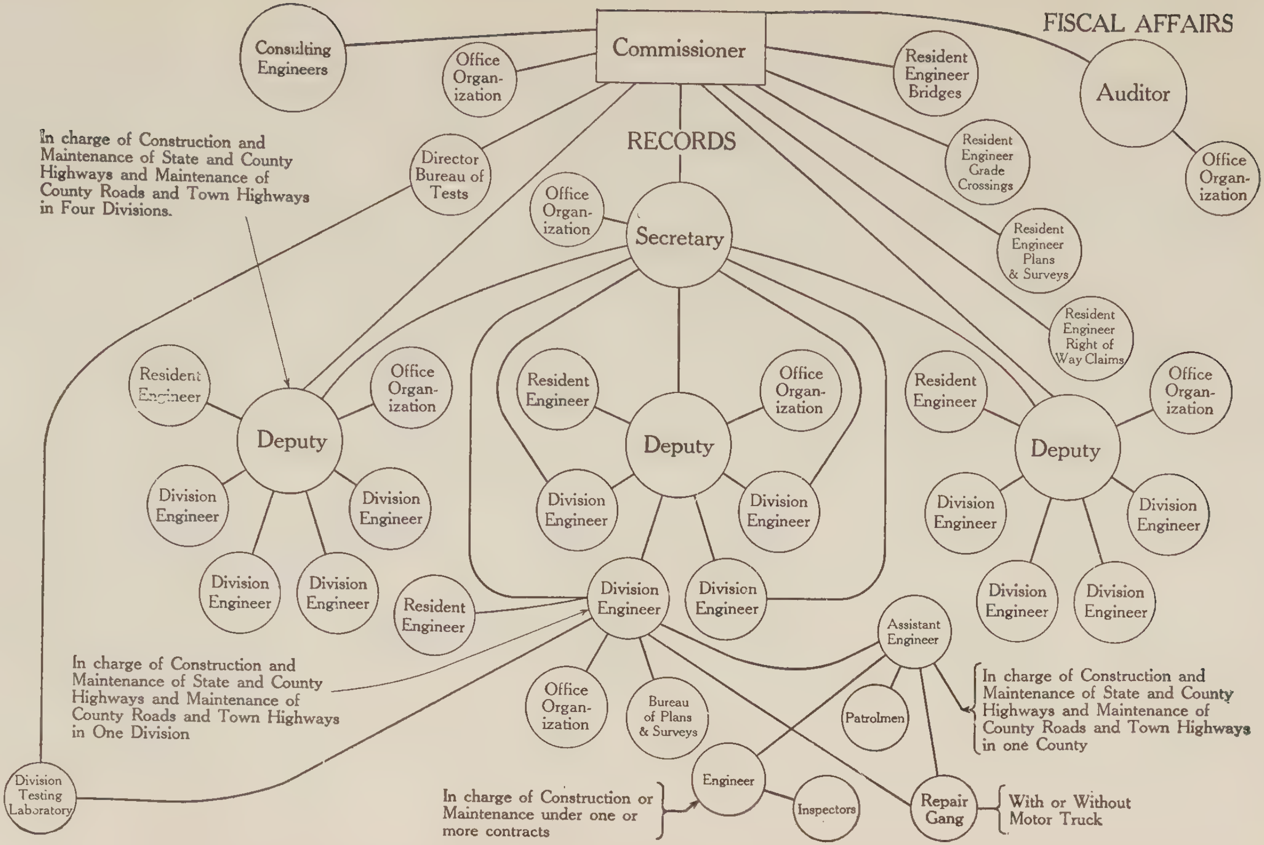

FISCAL AFFAIRS
Commissioner
Consulting Engineers
Office Organization
Resident Engineer Bridges
Auditor
Office Organization
RECORDS
Director Bureau of Tests
Resident Engineer Grade Crossings
Resident Engineer Plans & Surveys
Resident Engineer Right of Way Claims
Secretary
Office Organization
In charge of Construction and Maintenance of State and County Highways and Maintenance of County Roads and Town Highways in Four Divisions.
Deputy
Resident Engineer
Office Organization
Division Engineer
Division Engineer
Division Engineer
Division Engineer
Deputy
Resident Engineer
Office Organization
Division Engineer
Division Engineer
Division Engineer
Division Engineer
Deputy
Resident Engineer
Office Organization
Division Engineer
Division Engineer
Division Engineer
Division Engineer
Resident Engineer
Assistant Engineer
In charge of Construction and Maintenance of State and County Highways and Maintenance of County Roads and Town Highways in One Division
Office Organization
Bureau of Plans & Surveys
Patrolmen
In charge of Construction and Maintenance of State and County Highways and Maintenance of County Roads and Town Highways in one County
Division Testing Laboratory
Engineer
Inspectors
Repair Gang
With or Without Motor Truck
In charge of Construction or Maintenance under one or more contracts

Fig. 1

under civil service regulations, and in order to secure the greatest possible efficiency and widest competition for positions no residence qualifications should apply to any position.

The foregoing fundamental principles are embodied to a greater or less extent in the existing highway departments of the various states. Fig. 1 shows a proposed state highway department organization that was recommended for adoption by Blanchard and Hubbard while serving as the Advisory Board on Highways to the Department of Efficiency and Economy of the State of New York.

13. Fundamentals of Administration of Highway Departments.—As laid down by Nelson P. Lewis, former Chief Engineer to the Board of Estimate and Apportionment of New York City, the following requisites are necessary in order to secure satisfactory results in highway administration: (1) Authority over and responsibility for all work relating to highways within the administrative district should be centralized. (2) The organization should have sufficient flexibility to permit a concentration of force on any work of pressing importance. (3) Administrative units should be sufficiently large to permit the utilization of an entire force and equipment all of the time, reducing overhead charges to a minimum consistent with efficiency and thoroughness. (4) The prevalent horror of a bureaucracy is unfounded. If such a bureaucracy works well, it is a good thing. If it works badly, it is not because it is a bureaucracy, but because it is not well organized. (5) There should be direct and undivided responsibility for every part of the work; each head of a bureau or subdivision should be made to realize, however, that his own particular work should be so done as to help and not to hinder that of other bureaus or divisions. (6) Promotion to the headship of bureaus and departments should be made from within the organization when possible, not necessarily according to seniority, but by reason of peculiar fitness. When it is necessary to go outside of the organization to fill such a place, the appointee should be one who has already made good in similar work in some other place.

(7) There should be permanent tenure of office for those in responsible charge, so that continuity of purpose and policy may be assured.

TERMINOLOGY OF HIGHWAY ENGINEERING

14. General Considerations.—The terms in the following glossary are commonly used in highway engineering. The glossary should be carefully read in order to become familiar with the meaning of words and phrases repeatedly encountered in highway engineering literature, and in the course of study should be consulted every time a new term occurs the meaning of which is not clear.

15. Key to American Terminology.—In the accompanying glossary, the society, committee, or individual proposing or adopting each definition is indicated by the characters shown in the following key:

*Adopted by the American Society for Testing Materials.

†Proposed by the Special Committee on Materials for Road Construction, of the American Society of Civil Engineers.

‡Proposed by Committee D-4, on Road and Paving Materials, of the American Society for Testing Materials.

**Adopted by the American Railway Engineering Association.

‡‡Proposed by Prévost Hubbard.

GLOSSARY

Aggregate.—‡The inert material, such as sand, gravel, shell, or broken stone, or combinations thereof, with which the cementing material is mixed to form a mortar or concrete.

Asphalt.—Solid or semisolid native bitumens, solid or semisolid bitumens obtained by refining petroleums, or solid or semisolid bitumens which are combinations of the two classes of bitumens mentioned with petroleums or derivatives thereof, which melt on the application of heat, and which consist of a mixture of hydrocarbons and their derivatives of complex structure.

Asphalt-Block Pavement.—†One having a wearing course of previously prepared blocks of asphaltic concrete.

Asphalt Cement.—†A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements, and having a penetration of between 5 and 250. NOTE: Commonly designated in paving work as *A. C.*

Asphaltic.—†Similar to or essentially composed of asphalt.

Asphaltic Petroleum.—‡‡Petroleum which, upon evaporation or fractional distillation without blowing, will yield an asphalt cement.

Bank Gravel.—‡Gravel found in natural deposits, usually more or less intermixed with fine material, such as sand or clay, or combinations thereof; the terms gravelly clay, gravelly sand, clayey gravel, and sandy gravel indicate the varying proportions of the materials in the mixture.

Base.—†Artificial foundation.

Binder.—†(1) A foreign or fine material introduced into the mineral portion of the wearing surface for the purpose of assisting the road metal to retain its integrity under stress, as well as, perhaps, to aid in its first construction. (2) The course, in a sheet-asphalt pavement, frequently used between the concrete foundation and the sheet-asphalt mixture of graded sand and asphalt cement.

Bitumen.—*†A mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide.

Bituminous Aggregate.—‡‡A mineral or other aggregate containing bitumen as a cementing medium.

Bituminous Cement.—†A bituminous material suitable for use as a binder, and having cementing qualities which are dependent mainly on its bituminous character.

Bituminous-Concrete Pavement.—†One composed of broken stone, broken slag, gravel, or shell, with or without sand, Portland cement, fine inert material, or combinations thereof, and a bituminous cement incorporated together by a mixing method.

Bituminous Emulsion.—‡A liquid mixture in which minute globules of bitumen are held in suspension in water or in watery solution.

Bituminous Filler.—‡‡Bituminous material primarily used for filling the joints in bricks, block, concrete, or other pavements.

Bituminous-Macadam Pavement.—†One having a wearing course of macadam with the interstices filled by a penetration method with a bituminous binder.

Bituminous Mastic.—‡‡A bituminous aggregate, the mineral portion of which consists of very fine particles.

Bituminous Material.—†Material containing bitumen as an essential constituent.

Liquid Bituminous Materials.—*Those having a penetration at 25° centigrade (77° Fahrenheit), under a load of 50 grams applied for 1 second, of more than 350.

Semi-Solid Bituminous Materials.—*Those having a penetration at 25° centigrade (77° Fahrenheit), under a load of 100 grams applied for 5 seconds, of more than 10, and a penetration at 25° centigrade (77° Fahrenheit), under a load of 50 grams applied for 1 second, of not more than 350.

Solid Bituminous Materials.—*Those having a penetration at 25° centigrade (77° Fahrenheit), under a load of 100 grams applied for 5 seconds, of not more than 10.

Bituminous Pavement.—†One composed of broken stone, broken slag, gravel, shell, sand or fine inert material, or combinations thereof, and bituminous cement incorporated together.

Bituminous Rock.—‡‡Rock naturally impregnated with petroleum or asphalt.

Bituminous Surface.—†A superficial coat of bituminous material with or without the addition of stone or slag chips, gravel, sand, or material of similar character.

Blanket.—†See Carpet.

Bleeding.—†The exudation of bituminous material on the roadway surface after construction.

Bond.—†The combined action of inertia, friction, and of the forces of adhesion and cohesion which helps the separate particles composing a crust or pavement to resist separation under stress. Mechanical bond is the bond produced almost wholly, in a well-built broken-stone macadam road, by the interlocking of angular fragments of stone and the subsequent filling of the remaining interstices with the finer particles.

Borrow Pit.—**An excavation made for the purpose of obtaining material.

Bound.—†Bonded.

Bituminous-Bound.—†Bonded with the aid of bituminous material.

Water-Bound.—†Bonded with the aid of water.

Bridge.—†A structure for the purpose of carrying traffic over a gap in the roadbed measuring 10 feet or more in the clear span.

Camber of a Road.—†See Crown.

Carpet.—†A bituminous surface of appreciable thickness, generally formed on top of a roadway by the application of one or more coats of bituminous material with gravel, sand, or stone chips added.

Cement.—†An adhesive substance used for uniting particles of other materials to each other. Ordinarily applied only to calcined cement rock, or to artificially prepared, calcined, and ground mixtures of limestone and silicious materials. Sometimes used to designate bituminous binder used in bituminous pavement, when the expression bituminous cement is understood to be meant.

Cement Concrete.—†An intimate mixture of gravel, shell, slag, or broken stone particles with certain proportions of sand, or similar material, cement, and water, made previous to placing.

Cement-Concrete Pavement.—†One having a wearing course of hydraulic cement concrete.

Cemented.—†Bonded. Referring to water-bound macadam, the term cemented is used to designate that condition existing when, after rolling the stone forming the crust, the remaining voids have been filled with the finer sizes, and the

stone dust or flour has, under the action of water, taken a set, as does cement itself.

Chips.—†Small angular fragments of stone or slag containing no dust.

Clay.—†Finely divided earth, generally silicious and aluminous, which will pass a 200-mesh sieve.

Clearing.—**Removing natural and artificial perishable obstructions to grading.

Coal Tar.—The mixture of hydrocarbon distillates produced in the destructive distillation of coal.

Coat.—†See Carpet. The total result of one or more single surface applications.

Coke-Oven Tar.—*†Coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.

Consistency.—*†The degree of solidity or fluidity of bituminous materials.

Course.—†One or more layers of road metal spread and compacted separately for the formation of the road or pavement. Courses are usually referred to in the order of their laying as first course, second course, third course, etc. Also, a single row of blocks in a pavement.

Creosoting Oil.—‡‡Tar distillates, tars, and mixtures of tars with tar distillates which are used by a process of impregnation in the preservation of wood.

Crown.—†The rise in cross-section from the lowest to the highest part of the finished roadway. It may be expressed either as so many inches, or tenths of a foot, or as a rate per foot of distance from side to center, for example, the crown is 4 inches, or the crown is ½ inch to the foot.

Crust.—†That portion of a macadam or similar roadway above the foundation, consisting of the road metal proper with its bonding agent or binder.

Culvert.—†A structure for carrying traffic over a gap in the roadbed, measuring less than 10 feet in clear span.

Cut-Back Products.—*Petroleum, or tar residuums, which have been fluxed with distillates.

Dehydrated Tars.—*†Tars from which all water has been removed.

Ditch.—†The open side drain of a roadway, usually deep in proportion to its width, and unpaved.

Drainage.—†Provisions for the disposition of water. See Subdrainage, Surface Drainage, and V Drainage.

Dust.—†(1) Earth or other matter in fine, dry particles so attenuated that they can be raised and carried by air currents. (2) The product of the crusher passing through a fine sieve.

Dust Layer.—†Material applied to a roadway for temporarily preventing the formation or dispersion, under traffic, of distributable dust.

Embankment or Fill.—**A bank of earth, rock, or other material constructed above the natural ground surface.

Emulsion.—†A combination of water and oily material made miscible with water through the action of a saponifying or other agent. See Bituminous Emulsion.

Excavation or Cutting.—**(1) The cutting down of a natural ground surface; (2) the material taken from cuttings, borrow pits, or foundation pits; (3) the space formed by removing material.

Expansion Joint.—†A separation of the mass of a structure, usually in the form of a joint filled with elastic material, which will provide opportunity for slight movement in the structure.

Fat.—†Containing an excess; a fat asphalt mixture is one in which the asphalt cement is in excess and the excess is clearly apparent.

Filler.—†(1) Relatively fine material used to fill the voids in the aggregate. (2) Material used to fill the joints in a brick or block pavement.

Flushing.—†(1) Completely filling the voids. (2) Washing the pavement with an excess of water.

Flux.—*†Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.

Foundation.—†The portion of the roadway below and supporting the crust or pavement.

Artificial Foundation.—†That layer of the foundation especially placed on the subgrade for the purpose of

reinforcing the supporting power of the latter itself, and composed of material different from that of the subgrade proper.

Natural Foundation.—†The natural earthy material below and supporting the artificial foundation or, if there is no artificial foundation, the crust or pavement.

Gas-House Coal Tar.—*†Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Grade.—†(1) The profile of the center of the roadway, or its rate of rise or fall. (2) Elevation. (3) To establish a profile by cuts and fills for earthwork. (4) To arrange by sizes broken stone, gravel, sand, or combinations of such materials.

Gravel.—†Small stones or pebbles usually found in natural deposits more or less intermixed with sand, clay, etc., but in which mixture the particles which will not pass a 10-mesh sieve predominate.

Pea Gravel.—†Clean gravel the particles of which approximate peas in size.

Grit.—†‡Stone chips, slag chips, or small gravel.

Grout.—**A mortar of liquid consistency which can easily be poured.

Grubbing.—**Removing stumps and roots.

Gumbo.—**A term commonly used for a peculiarly tenacious clay, containing no sand.

Gutter.—†The artificially surfaced and generally shallow waterway provided usually at the sides of the roadway for carrying surface drainage. Occasionally used synonymously with ditch, but incorrectly so, as gutters are always paved or otherwise surfaced, and ditches are not.

Haunches.—†The sides or flanks of a roadway. Sometimes also called quarters.

Highway.—†The entire right of way devoted to the public travel, including the sidewalks and other public spaces, if such exist.

Humus.—Soil formed by the decomposition of vegetable matter on the surface of the ground.

Intercepting Ditch.—**An open artificial waterway for preventing surface water from flowing over the slopes of a cut or against the foot of an embankment.

Loam.—†‡Finely divided earthy material containing a considerable proportion of organic matter.

Macadam.—†A road crust composed of stone or similar material broken into irregular angular fragments compacted together so as to be interlocked and mechanically bound to the utmost possible extent.

Mastic.—†A mixture of bituminous material and fine mineral matter suitably made for use in highway construction and for application in a heated condition.

Mat.—†See Carpet.

Matrix.—*†The binding material or mixture of binding material and fine aggregate in which the large aggregate is embedded or held in place.

Mesh.—†‡The square opening of a sieve.

Native Asphalt.—*Asphalt occurring as such in nature.

Normal Temperature.—†‡As applied to laboratory observations of the physical characteristics of bituminous materials, is 25° centigrade (77° Fahrenheit).

Oil Asphalt.—‡‡Asphalt manufactured directly from petroleum.

Overhaul.—**The number of cubic yards moved through the overhaul distance multiplied by the overhaul distance in units of 100 feet.

Overhaul Distance.—**The distance beyond the free-haul limit that material is hauled in constructing the roadway, for which extra compensation is allowed.

Palliative.—†A short-lived dust layer.

Paraffin Petroleum.—‡‡Petroleum which, upon evaporation or fractional distillation, will yield a greasy residue containing an appreciable quantity of paraffin hydrocarbons.

Patching.—†Repairing or restoring small isolated areas in the surface of the metaled or paved portion of the highway.

Pavement.—†The wearing course of the roadway or footway, when constructed with a cement or bituminous binder,

or composed of blocks or slabs, together with any cushion or binder course.

Penetration.—‡The consistency of a bituminous material, expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. Where the conditions of test are not specifically mentioned, the load, time, and temperature are understood to be 100 grams, 5 seconds, and 25° centigrade (77° Fahrenheit), respectively, and the units of penetration to indicate hundredths of a centimeter.

Penetration Method.—†The method of constructing a bituminous macadam pavement by pouring or grouting the bituminous material into the upper course of the road material before the binding of the latter has been completed.

Petroleum.—‡Liquid bitumen occurring as such in nature.

Pitch.—*†Solid residue produced in the evaporation or distillation of bitumens, the term being usually applied to residue obtained from tar.

> *Hard Pitch.*—†Pitch showing a penetration of not more than ten.
>
> *Soft Pitch.*—†Pitch showing a penetration of more than ten.

Pocket.—†A hole or depression in the wearing course.

Pot Hole.—†A hole extending below the wearing course.

Profile.—†A longitudinal section of a highway, generally taken along the center line.

Quarters.—†The four sections of equal width which, side by side, make up the total width of a roadway.

Raveling.—†The loosening of the metal composing the crust.

Refined Asphalt.—‡‡Asphalt that has been subjected to a refining process, but which is ordinarily too hard for use in the manufacture of bituminous pavements until softened by combining it with a flux. NOTE: Commonly designated in paving work as *R. A.*

Refined Tar.—*†A tar freed from water by evaporation or distillation which is continued until the residue is of desired

consistency; or a product produced by fluxing tar residuum with tar distillate.

Renewals.—†Extensive repairs over practically the whole surface of the metaled or paved portion of the highway.

Repairs.—†The restoration or mending of a considerable amount of the metaled or paved portion of the highway, but not usually of the larger part of the surface area. More extensive than *patching* but less so than *renewals*.

Resurfacing.—†The renewal of the surface of the crust or pavement.

Road.—†A highway outside of an urban district.

Roadbed.—†The natural foundation of a roadway.

Road Metal.—†Broken stone, gravel, slag, or similar material used in road and pavement construction and maintenance.

Roadway.—†That portion of a highway particularly devoted to the use of vehicles.

Rock Asphalt.—†‡Sandstone or limestone naturally impregnated with asphalt.

Rock-Asphalt Pavement.—†A wearing course composed of broken or pulverized rock asphalt with or without the addition of other bituminous materials.

Sand.—†Finely divided rock detritus, the particles of which will pass a 10-mesh and be retained on a 200-mesh screen.

Sand-Clay Road.—†A roadway composed of an intimate mixture of sand and clay.

Scarify.—†To loosen and disturb superficially.

Screen.—†In laboratory work, an apparatus, in which the apertures are circular, for separating sizes of material.

Screenings.—‡Broken rock, including the dust, of a size that will pass through a $\frac{1}{2}$- to $\frac{3}{4}$-inch screen, depending upon the character of the stone.

Seal Coat.—†A final superficial application of bituminous material to a bituminous pavement during construction.

Setting Up.—†As applied to bituminous material, the relatively quick change which takes place after its application to a roadway, indicated by its hardening after cooling and exposure to atmospheric and traffic conditions, as opposed

to the slower changes later occurring gradually and almost imperceptibly.

Shaping.—†Trimming up and preparing a subgrade preparatory to applying the first course of the road metal or artificial foundation.

Sheet-Asphalt Pavement.—†One having a wearing course composed of asphalt cement and sand of predetermined grading, with or without the addition of fine material, incorporated together by a mixing method.

Sheet Pavement.—†A pavement free from frequent joints such as would accompany small slabs or blocks, and which has an appreciable thickness, say in excess of 1 inch on the average, for its wearing course.

Shoulders.—†The portion of the highway between the edges of the road metal or pavement and the gutters, slopes, or watercourse.

Side Drainage.—†That along the sides of a roadway.

Sidewalk.—†The portion of the highway reserved for pedestrians.

Sieve.—†In laboratory work, an apparatus, in which the apertures are square, for separating sizes of material.

Silt.—†Naturally deposited fine earthy material, which will pass a 200-mesh sieve.

Soil.—*A mixture of fine earthy material, with more or less organic matter, resulting from the growth and decomposition of vegetable or animal matter.

Squeegee.—†A tool with a rubber or leather edge for scraping or cleaning hard surfaces, or for spreading and distributing liquid material over and into the superficial interstices of roadways.

Squeegee Coat.—†An application by means of the squeegee.

Stone-Block Pavement.—†One having a wearing course composed of stone blocks quite or nearly rectangular in shape.

Stone Chips.—*Small angular fragments of stone containing no dust.

Street.—†A highway in an urban district.

Subdrain.—**A covered drain, below the roadbed or ground surface, receiving the water along its length by absorption or through the joints.

Sub, or Under, Drainage.—†That below the surface.

Subgrade.—†The upper surface of the native foundation on which is placed the road metal or the artificial foundation.

Superficial Coat.—†A light surface coat.

Surface Drainage.—†That on a roadway or ground surface.

Surface Treatment.—†Treating the finished surface of a roadway with bituminous material.

Surfacing.—†(1) The crust or pavement. (2) Constructing a crust or pavement. (3) Finally finishing the surface of a roadway. (4) Treating the surface of a finished roadway with a bituminous material.

Tailings.—*†Stones which, after going through the crusher, do not pass through the largest openings of the screen.

Tar.—*†Bitumen which yields pitch upon fractional distillation and which is produced as a distillate by the destructive distillation of bitumens, pyro-bitumens, or organic material.

Telford.—†Properly, an artificial foundation advocated by Thomas Telford (1757–1820), and consisting of a pavement of stone about 8 inches thick, laid by hand, and closely packed and wedged together. The individual stones were desired to be about 16 square inches in section, and about 8 inches in length. They were placed close together on the prepared subgrade, their longest dimension vertical, and on their larger ends, their interstices chinked with smaller stones, and the whole rammed, or rolled, until firm and unyielding.

Telford Macadam.—†Macadam with an artificial foundation of Telford.

Up-Keep.—†Maintenance.

V Drainage.—†That provided by the construction of troughs in the subgrade of the roadway, which troughs are like a **V**, with flat sloping sides, and are filled with stone.

Viscosity.—†‡The measure of the resistance to flow of a given amount of the material through a given orifice.

Volatile.—†Applied to those fractions of bituminous materials which will evaporate at climatic temperatures.

Waste or Spoil Banks.—**Banks outside the roadway formed by waste.

Water-Gas Tars.—*†Tars produced by cracking oil vapors at high temperatures in the manufacture of carburetted water gas.

Wearing Coat.—†The superficial layer of the crust or pavement exposed to traffic.

Wearing Course.—†The course of the crust or pavement exposed to traffic.

Wood-Block Pavement.—†One having a wearing course composed of wood paving blocks, generally rectangular in shape.

CITY SURVEYING

MEASURING INSTRUMENTS AND METHODS

INTRODUCTION

1. The surveying work to be done by a city engineer or surveyor includes surveys for street, block, and lot grading; surveys for sewers, buildings, waterworks, bridges, and other structures; surveys for street railways; and land surveys. The land surveys may be small in extent, embracing the location of a single small lot, or they may be extensive, including the subdivision of large tracts of land into streets and building lots. Lot surveys in a large city compactly built on irregular lines are often very difficult, and demand not only very great precision, but a good deal of ingenuity in overcoming obstacles. The lines must not infrequently be carried over the tops of houses to determine interior angle points, each case presenting new problems not to be foreseen, and requiring much skill and judgment for their solution.

Surveys for the various forms of construction, for grades, etc. require no greater degree of precision than similar surveys out of a city, except where the determination of land lines is involved, as in laying out a building whose walls are to be erected exactly on the lot lines. Such surveys require the same degree of precision as city land surveys. This precision depends on the importance and value of the property. The value of 1 square foot of land in the country may be from less than $\frac{1}{16}$ cent to a probable maximum of 4 or 5 cents,

while in the heart of a large city a single square foot may be worth several hundred dollars. An error of 1 inch in the location of the wall of a modern high office building may be a very serious matter. The corner of a farm may be anywhere inside a tree 2 or 3 feet in diameter; the corner of an important city lot must be determined within the diameter of a builder's chalk line.

LINEAR MEASUREMENTS

2. The Tape.—Tapes of various kinds are described in *Chain Surveying*. The steel tape is the standard instrument for linear measurements in city work. The usual lengths are 50 and 100 feet. The tape may be graduated into feet, tenths, and hundredths; into feet and tenths; into whole feet with the divisions at the ends subdivided into tenths and hundredths; or in any other convenient manner. The manufacturer will graduate the tape to order.

Each time the tape is brought in after being used, it should be cleaned, if very dirty, with waste or a dry rag, and then carefully wiped off with a piece of cloth or chamois and a very small quantity of some non-gumming oil.

The tape has sometimes attached to it a handle that contains a spring balance for measuring the pull on the tape, a level bubble to guide in holding the tape so it will be level, and a thermometer to show the temperature of the tape. The thermometer scale may be so made as to indicate the proper pull to be exerted on the tape to make it of standard length for the temperature indicated. It is a question, however, whether such a scale can be relied on for precision, and hence its utility is of doubtful value.

3. Marking Pins.—The marking pins, where any are used, may be shorter and lighter than those used in country surveys. Pins 6 to 8 inches long made of No. 10 or No. 12 wire are good. In the larger cities, pins cannot be used, and lengths are indicated by knife scratches or pencil marks on the stone curb or pavement. A hard scratch awl answers the purpose very well.

CORRECTIONS

4. To measure a line with a high degree of precision is not difficult, but requires great care. In small town work, the absolute length of the tape is not usually known or required to a greater degree of precision than is furnished by the maker. The tapes sent out from reliable makers are compared with standards and may be assumed to be standard length when straightened out tight, with no stretching pull, at the temperature stated by the maker—usually 62° F. For important city work, the temperature at which the tape is exactly its graduated length should be determined by a test in a responsible testing laboratory, such as the Bureau of Standards in Washington, which for a small charge will furnish the constants of temperature and pull for any tape.

5. Correction for Temperature.—When the temperature of a tape rises, the tape expands or lengthens; when the temperature falls, the tape contracts. The proportion of its own length by which a tape changes in length for a change of 1° of temperature is called the **coefficient of expansion**, or **temperature coefficient**, of the tape. When practicable, the coefficient of expansion should be directly determined for each tape. For a steel tape whose coefficient is not known, .0000065 may be taken as an approximate value. That is, for an increase of 1° in temperature, the tape will increase in length by $\frac{65}{10000000}$ of its length, and will similarly shorten for a decrease of 1°.

Let t_0 = temperature at which a tape of length L_0 is **standard**—that is, at which the actual length of the tape is the length L_0 indicated by the figures on the graduations;

c = coefficient of expansion of tape;

L = length of tape at any temperature t.

Then, the *algebraic* increase in the length of the tape will be

$$cL_0 \times (t - t_0);$$

and, therefore, $$L = L_0 + (t - t_0)cL_0 \qquad (1)$$

The true length of every foot division of the tape will be $1 + c(t - t_0)$. Therefore, if the length of a line, as measured with and indicated by the tape, is l, and the true length of the line is l_0, we must have

$$l_0 = l[1 + c(t - t_0)] = l + c(t - t_0)l \qquad (2)$$

If t is less than t_0, the correction $c(t - t_0)$ is negative, which shows that l_0 is less than l. This is otherwise evident, since in this case the tape contracts, and therefore the indicated length is greater than the true length.

EXAMPLE.—A line was measured with a tape that was standard at 62°. The temperature was 90°. The length, as measured, was 502.34 feet. If the coefficient of expansion of the tape was .0000065, what was the true length of the line?

SOLUTION.—Here

$$c(t - t_0) = .0000065 \times (90 - 62) = .000182$$

The correction $c(t - t_0)l$ is, practically, $.000182 \times 502$, the decimal .34 being dropped, as the product of it by .000182 is too small to be considered. Therefore,

$$l_0 = 502.34 + .000182 \times 502 = 502.43 \text{ ft.} \quad \text{Ans.}$$

6. Correction for Pull.—Within the elastic limit of the material of which a tape is made, the tape will stretch proportionally to the pull on it. If P is the pull on the tape and A is the area of cross-section, the unit stress S equals $\frac{P}{A}$.

Also, the elongation per unit length e equals the unit stress divided by the modulus of elasticity E, or $e = \frac{S}{E}$. Then if the length of the tape is denoted by L, the total elongation d equals $eL = \frac{S}{E}L$. Hence, substituting $\frac{P}{A}$ for S,

$$d = \frac{P}{EA}L \qquad (1)$$

Therefore, the true length L_0 of the stretched tape is given by the formula

$$L_0 = L + \frac{P}{EA}L \qquad (2)$$

If the length of a line as measured with the stretched tape is l, and the true length of the line is l_0, then

$$l_0 = l + \frac{P}{EA} l \qquad (3)$$

For such steel as tapes are made of, E may be assumed without great error as 28,000,000 pounds per square inch. A not unusual cross-section is about .002 square inch. A tape 100 feet long with such a cross-section would be lengthened about .036 foot for a pull of 20 pounds above the normal. Hence, a line measured with such a tape under such a pull, and found to be 400 feet long, would really be $400 + 4 \times .036 = 400.144$ feet long.

7. Correction for Sag.—If a tape is held off the ground so that it is supported only at each end, it will sag and hang in a curve. Now, should the actual distance between the two supports, that is, the length of the chord made by the curve of the tape, be taken as equal to the nominal length of the tape, an error is made equal to the difference between the length of the arc and the chord of that arc. It is true that the tape may be pulled so hard that most of the sag may be taken out, but it is a physical impossibility to pull it so strongly as absolutely to remove all the sag. It is not difficult, however, to stretch the tape so as to take up most of the sag and make the nominal or graduated length of the tape practically equal to the true distance on the chord between the end graduations. The effect of sag in shortening the distance between end graduations depends on the weight and length of the unsupported part of the tape, and on the pull exerted at the ends of the tape. The derivation of a formula for this effect, which may be called the **correction for sag,** involves principles of advanced mathematics, and here only the formula itself will be given.

If L_0 = unsupported length of tape;

w = weight of tape per unit of length;

P = pull;

the shortening s due to the sag is given by the formula

$$s = \frac{w^2 L_0^3}{24 P^2} \qquad (1)$$

It should be observed that L_0 is the length of the *unsupported part*, which may not be the entire length of the tape.

Since, when the tape sags, the distance between its two supports, as indicated by the nominal length of the tape, is greater than the actual distance, or the length of the chord subtended by the arc, the correction for the sag is negative, and must be subtracted from the nominal length indicated by the tape. If the length of a line, as measured, contains n times the length L_0, and the sag is the same in all measurements, the correction for sag is

$$n s = \frac{n w^2 L_0^3}{24 P^2} \qquad (2)$$

EXAMPLE.—A line as measured with a 100-foot tape weighing .007 pound per foot, with a pull of 14 pounds, is found to be 400 feet. To determine the correction for sag.

SOLUTION.—Here, $n = 4$; $w = .007$, $L_0 = 100$; and $P = 14$. Substituting these values in formula 2,

$$n s = \frac{4 \times .007^2 \times 100^3}{24 \times 14^2} = .042 \text{ ft. Ans.}$$

8. **Pull Necessary to Neutralize the Sag.**—If it is desired to pull the tape just enough to cause the stretch, which is a positive error, to balance the sag, which is a negative error, the proper pull may be found by equating the expression for stretch (Art. 6) to that for sag, and solving the resulting equation for the pull P; thus:

$$\frac{P L_0}{A E} = \frac{w^2 L_0^3}{24 P^2};$$

whence $$P^3 = \frac{A E}{24} w^2 L_0^2;$$

and, therefore, $$P = \sqrt[3]{\frac{w^2 L_0^2 A E}{24}}$$

As already stated, L_0 is the unsupported length of the tape, not necessarily the whole length.

EXAMPLE.—The weight of a 100-foot tape is .008 pound per foot, and the sectional area is .002 square inch. Taking E as 28,000,000 pounds per square inch, determine the pull necessary to neutralize the sag.

SOLUTION.—In this example, $w = .008$, $L_0 = 100$, $A = .002$, and $E = 28{,}000{,}000$. Substituting these values in the formula,

$$P = \sqrt[3]{\frac{.008^2 \times 100^2 \times .002 \times 28{,}000{,}000}{24}} = 11.4 \text{ lb.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

1. A line is measured at a temperature of 80° and found to be 870.45 feet long. If the tape used is standard at a temperature of 60°, what is the true length of the line, taking the coefficient of expansion as .0000065? Ans. 870.56 ft.

2. What is the true length of a 100-foot tape, .002 square inch in cross-section, under a pull of 18 pounds, assuming the coefficient of elasticity to be 28,000,000 pounds per square inch? Ans. 100.032 ft.

3. What is the error due to sag in one-half of a 100-foot tape whose weight is .007 pound per foot, under a pull of 20 pounds? Ans. .003 ft.

4. What pull is necessary to neutralize the sag in a 50-foot tape whose sectional area is .002 square inch and weight .008 pound per foot? Assume the coefficient of elasticity to be 28,000,000 pounds per square inch. Ans. 7.2 lb.

MEASURING ON SLOPING GROUND

9. General Method.—In measuring on a slope, the method described in *Chain Surveying* may be used, if not very accurate results are desired. For very accurate work, it is preferable to measure directly along the slope, and then reduce the results to horizontal measurement. The process is illustrated in Fig. 1, where it is desired to determine the horizontal distance d $(= AH)$ between the points A and C.

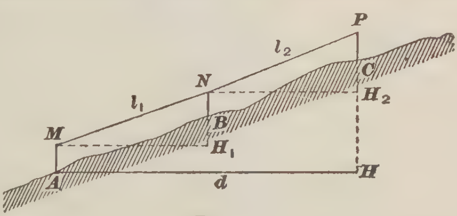


FIG. 1

Stakes are driven at A and C, and at as many intermediate points as necessary, so that the distance between two consecutive stakes can be conveniently measured with the tape. In the case here assumed, there is an intermediate stake at B. The inclined distances l_1 $(= MN)$ and l_2 $(= NP)$

between tacks on the tops of the stakes are carefully measured with the tape. The differences of elevation $h_1 (= NH_1)$ and $h_2 (= PH_2)$ are determined by leveling. Then,

$$d = MH_1 + NH_2 = \sqrt{l_1^2 - h_1^2} + \sqrt{l_2^2 - h_2^2}$$

The same method applies when there are any number of intermediate stakes.

10. Special Case.—When the slope of the ground is very gentle, the difference in elevation between two points is relatively small, and the horizontal distance does not differ very materially from the inclined. Under such conditions, the following formula gives sufficiently close results: Let l, Fig. 2, be the inclined distance between two points A and B whose difference h in elevation is small. Let the horizontal distance AC be denoted by d, and the difference $l - d$ by k, so that

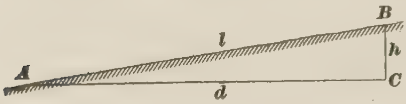


FIG. 2

$$d = l - k \qquad (1)$$

In the right triangle ABC,

$$l^2 - d^2 = h^2, \text{ or } l^2 - (l - k)^2 = h^2;$$

that is,

$$2\,lk - k^2 = h^2;$$

or, approximately, since k^2 is very small,

$$2\,lk = h^2; \text{ whence } k = \frac{h^2}{2\,l}$$

This value in equation (1) gives

$$d = l - \frac{h^2}{2\,l}$$

ANGULAR MEASUREMENTS

11. The City Transit.—The transit is the only angle-measuring instrument employed in city surveys. The ordinary style of transit having a vernier reading to 30 seconds is the one most commonly used, though many are in use that read to minutes, a few that read to 20 seconds, and still fewer that are of special patterns. Since magnetic bearings,

except for rough checks, are used but very little, the needle may be dispensed with, and a stiff form of standards for the telescope may be made to bear directly over the center of the instrument, as shown in Fig. 3.

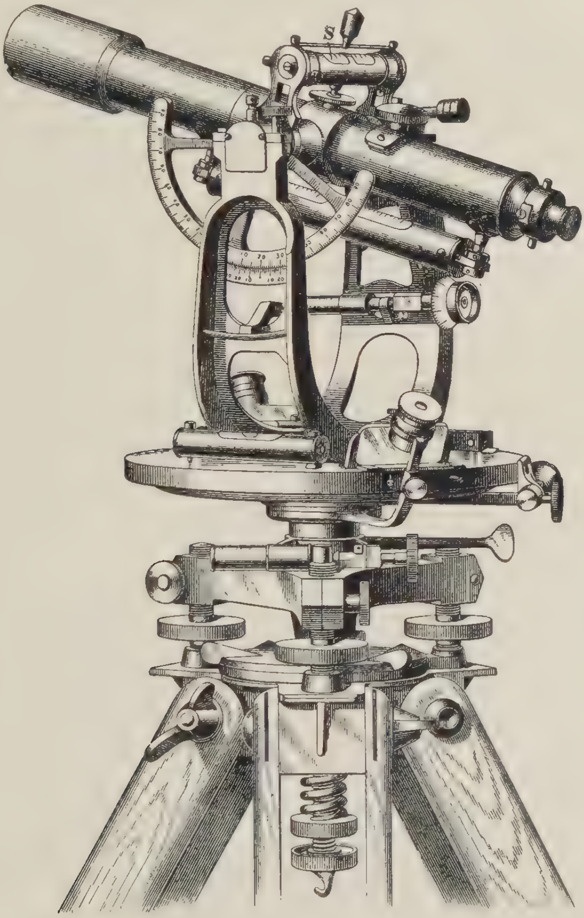


Fig. 3

The instrument shown has only three leveling screws, but four may be had if desired. It has also an inverting telescope; that is, the object looked at appears upside down and right side left. The three leveling screws give a broader

leveling base and a consequent greater precision in leveling; while the inverting telescope gives more light, and hence enables the operator to get a clearer conception of the object in view. The reason why the telescope gives more light is that the eyepiece is equipped with two instead of four lenses, and each lens absorbs some of the light rays that reach it. In the instrument shown in Fig. 3, the verniers have over them stationary glasses that are a great convenience in taking readings. The instrument is also equipped with a **striding level** *S*, which rests on the horizontal axis and is held in place by a screw in the center of the telescope. This striding level indicates at all times whether the transverse axis of the telescope is horizontal.

The striding level requires adjustment, as does any other level. The adjustment may be tested in the following manner: Place the striding level on the horizontal axis, and manipulate it with the lower screws until the bubble is in the center; then reverse the level end for end. If the bubble remains in the center, the level is in adjustment, and the transverse axis of the telescope is horizontal. If the bubble is not in the center, adjust the level with the screws provided for this purpose, lowering or raising one end until the bubble moves half way back to the center of the tube; then relevel with the leveling screws, and repeat for a check. There are adjusting screws for lateral adjustment, which is performed in the same way as the lateral adjustment of the wye level.

12. Every transit for city work should be provided with a vertical arc or circle, a clamp and slow-motion screw for the vertical motion of the telescope, and a bubble under the telescope. The vertical arc or circle should be fixed in position on the transverse axis, and should be provided with a vernier reading to minutes. The bubble under the telescope should be fairly sensitive, showing about 20 seconds of arc for a movement of the bubble over one division of the graduations on the tube. Fixed stadia wires set apart one one-hundredth of the focal length of the objective are desirable. The telescope should magnify not less than 22 diameters.

13. Line Rods.—The line rods used in city work should be of small diameter and perfectly straight. Probably the best rod is a $\frac{3}{8}$-inch hexagonal steel rod 6 feet long, painted in 1-foot lengths alternately red and white, and drawn to a sharp round point on one end used for the bottom, and to a blunt chisel point on the other. A chaining pin, a lead pencil, or a suspended plumb-line are often used instead of rods.

14. Measuring Angles.—For most surveying work, a single measurement of an angle with a minute-reading circle is sufficient, although every angle should be measured twice for a check; but in city work, angles are usually required to a smaller unit than the least reading of the vernier. These angles may be obtained by the **method of repetition** as follows: The transit is set up over the vertex of the angle with the verniers reading zero; the lower clamp being loosened and the upper set, the telescope is directed along the left-hand side of the angle. The lower clamp is then fastened, the upper loosened, and the telescope directed along the right-hand side of the angle. The upper clamp is now set, the vernier read, the lower clamp loosened, and the telescope directed along the left-hand side of the angle. The lower clamp is then set, the upper loosened, and the telescope directed along the right-hand side of the angle. The upper clamp is now set, the lower loosened, and the telescope directed again along the left-hand side of the angle; then the lower clamp is set, the upper loosened, and the telescope directed along the right-hand side of the angle. The process is repeated as often as necessary to obtain the required accuracy. The vernier is read after the final turning, when the telescope is set on the right-hand side of the angle, and the reading is divided by the number of turnings, including the first. The result will be the value of the angle, which, as a check, should closely approximate the first reading. This first reading is taken only for the purpose of checking the final result.

Theoretically, the number of measurements should be such that the sum will approximate a whole number of complete

revolutions, so that all parts of the circle may be used in measuring; but, practically, three measurements are sufficient in all ordinary cases. In very precise work, the angle may be read as described, and then read again from right to left with the telescope inverted. This eliminates errors of pointing and adjustment of the line of collimation.

15. Adjustment of Measured Angles of a Triangle. It is frequently necessary, in precise plane surveying, as in locating bridge piers, making topographical surveys of cities, etc., to measure triangles. When this need occurs, each angle of the triangle should be measured directly. If but two angles are measured and their sum is subtracted from 180° to get the third, all errors of measurement of the two angles are thrown into the third angle. When all the angles are measured to a high degree of precision, their sum will ordinarily be more or less than 180°, indicating an impossible triangle. To make the triangle possible, the angles are adjusted so that their sum shall be 180°. This adjustment is effected by dividing the total error equally among the three angles. It might seem that a distribution in some ratio to the size of the angles should be adopted; but the method applied considers that there is no more reason for making an error in measuring a large angle than in measuring a small angle, which is probably true. Much more elaborate methods of adjusting angles are used where a network of triangles occurs, as in geodetic surveying, but the treatment of such adjustments is beyond the scope of this work.

PRECISION

16. Mean Value.—If a quantity, as a distance or an angle, is measured very accurately several times by the same method, it is usually found that the results vary slightly from one another. The true measure of the quantity is taken to be the mean of the different results obtained—that is, the sum of these results divided by their number. This mean is called the **mean value,** or **most probable value,**

of the quantity. Thus, if a distance has been measured five times by the same method and under the same circumstances, and the results have been, respectively, 75.83, 75.81, 75.84, 75.81, and 75.82 feet, the mean value of the distance is

$$\frac{75.83 + 75.81 + 75.84 + 75.81 + 75.82}{5} = 75.822 \text{ feet}$$

In operations of this kind, much labor is saved by finding the mean of only those figures that are different for the different measurements, and adding the result to the common part. In the example given above, 75.8 is the common part; it is, therefore, sufficient to take the mean of .03, .01, .04, .01, and .02, which is

$$\frac{.03 + .01 + .04 + .01 + .02}{5} = \frac{.11}{5} = .022$$

The mean value is, then, 75.8 + .022 = 75.822 feet.

17. Probable Error.—The mean value of a quantity, determined as just explained, may not be the exact value of the quantity. There is a quantity, whose value is determined by a formula derived by higher mathematics, such that there is the same probability of the true error being less as of its being greater than that quantity. Such quantity is called the **probable error.** The probabilities are that the error committed in taking the mean for the true value does not exceed the probable error—hence the name of the latter quantity. The probable error serves as a measure of the accuracy of the results obtained by the use of the mean value.

If each of the values found by actual measurement is subtracted from the mean value, a series of differences v_1, v_2, v_3, etc., called **residuals,** will be obtained. Let the sum of the squares of these residuals be denoted by Σv^2, the number of measurements by m, and the probable error by p. Then,

$$p = \pm .6745 \sqrt{\frac{\Sigma v^2}{m(m-1)}}$$

If the mean value is denoted by M, the probabilities are that the true value lies between $M + p$ and $M - p$. The

expression $M \pm p$ is often written as the value of the quantity, the term $\pm p$ being added simply to indicate the limits between which the true value probably lies.

EXAMPLE.—A distance was measured four times, the results of the measurements being, respectively, 501.07, 501.06, 501.05, and 501.08 feet. To determine: (*a*) the mean value M of the distance; (*b*) the probable error p.

SOLUTION.—(*a*) Since 501 is common to all the measurements, we have

$$M = 501 + \frac{.07 + .06 + .05 + .08}{4} = 501.065. \quad \text{Ans.}$$

(*b*) To apply the formula for p, we have $m = 4$, $m - 1 = 3$, and

$$v_1 = 501.065 - 501.07 = -.005$$
$$v_2 = 501.065 - 501.06 = .005$$
$$v_3 = 501.065 - 501.05 = .015$$
$$v_4 = 501.065 - 501.08 = -.015$$
$$\Sigma v^2 = (-.005)^2 + (.005)^2 + (.015)^2 + (-015)^2 = .0005$$

Therefore, $p = \pm .6745\sqrt{\frac{.0005}{4 \times 3}} = \pm .0044$. Ans.

18. Weighted Measurements.— If the measurements are not made under the same conditions, so that there are reasons to believe that some of them are more accurate than others, the results must be *weighted*, as in the adjustment of notes for balancing a survey (see *Compass Surveying*, Part 2). That measurement whose accuracy is supposed to be the least is usually given a weight of 1; a measurement whose accuracy appears to be twice as great is given a weight of 2; etc. After the measurements have been weighed, each measurement is multiplied by the number representing its weight, the products are added, and the sum is divided by the sum of the weight numbers. This result is the mean value, or most probable value, of the quantity. Thus, in the example given in the last article, if the first measurement is of the least weight, while the second is twice as great as the first, and the third and fourth are each two and one-half times as great as the first, the weights of the four measurements are, respectively, 1, 2, 2.5, and 2.5, and the mean value M is

$$501.0 + \frac{.07 \times 1 + .06 \times 2 + .05 \times 2.5 + .08 \times 2.5}{1+2+2.5+2.5} = 501.064$$

Giving the weight 2 to a measurement is equivalent to counting that measurement as two equal measurements of weight 1; the weight 2.5 is equivalent to two and one-half equal measurements (if such a thing were conceivable) of weight 1; etc. Therefore, in the probable-error formula, the square of each residual should be multiplied by the weight attached to the corresponding measurement; the sum of the products is used instead of Σv^2, and the sum of the weights instead of m. If the weights are denoted by h_1, h_2, h_3, etc., their sum by Σh, and the sum of the products $h_1 v_1^2$, $h_2 v_2^2$, etc. by $\Sigma(h v^2)$, the formula for the probable error becomes

$$p = \pm .6745\sqrt{\frac{\Sigma(h v^2)}{(\Sigma h - 1)\Sigma h}}$$

EXAMPLE.—To determine the probable error p in the example of the preceding article, the weights of the four measurements being, respectively, 1, 2, 2.5, and 2.5.

SOLUTION.—The mean value M has been found to be 501.064. The values of the residuals are as follows:

$$v_1 = 501.064 - 501.07 = -.006$$
$$v_2 = 501.064 - 501.06 = +.004$$
$$v_3 = 501.064 - 501.05 = +.014$$
$$v_4 = 501.064 - 501.08 = -.016$$

Then,

$$\Sigma(h v^2) = 1 \times (-.006)^2 + 2 \times (+.004)^2 + 2.5 \times (+.014)^2 + 2.5 \times (-.016)^2 = .001198, \text{ and } (\Sigma h - 1)\Sigma h = 7 \times 8$$

Substituting in the formula,

$$p = \pm .6745\sqrt{\frac{.001198}{8 \times 7}} = \pm .0031. \quad \text{Ans.}$$

19. Measure of Precision.—It will be seen from what precedes that the probable error furnishes a useful index of the precision with which the observational work has been executed. It is customary to express precision in terms of the probable error: when it is said that a line has been measured with a precision of $\frac{1}{5000}$, it is usually meant that the probable error derived from the series of measurements is not numerically greater than $\frac{1}{5000}$ of the determined length of the line. Thus, in the example of Art. **17**, the precision was $.0044 \div 501.065 = \frac{1}{113878}$. When the measurements were assigned such weights as were assumed to be proper (Art. **18**), the precision was $.0031 \div 501.064 = \frac{1}{161634}$.

The student should distinguish carefully between *accuracy*, referring to freedom from *mistakes*, and *precision*, referring to *refinement* or *closeness* of measurement. Thus, work may be as accurately done with a transit reading to minutes as with one reading to half minutes, but the possible precision with the latter is the greater.

20. Precision Required.—In important cities, a precision of 1 in 50,000 should be obtained in land-surveying measurements; that is, the mean of two measurements of a given line should have a probable error of not more than $\frac{1}{50000}$ of the length of the line. This will generally be accomplished if the two measurements differ by not more than $\frac{3}{50000}$, or, say, $\frac{1}{16000}$, of the length of the line. This result is not very difficult to secure if the proper methods and instruments are used. In villages and small towns, a precision of $\frac{1}{5000}$ is ordinarily sufficient, but it is so easy to secure a better precision than this, that no two measurements of the same line should differ by more than $\frac{1}{10000}$ of its length, giving a precision of the mean of the two measurements of about $\frac{1}{30000}$.

21. Precision in Angular Measurements.—In order that the direction of a line may be determined so that a distant end shall not depart from its true position by not more than $\frac{1}{50000}$ of the length of the line, the angle on which the direction depends must be measured to about the nearest 4 seconds. A transit reading to 30 seconds will permit an approximation to this result if the mean of three readings of the angle is used. An instrument reading to 20 seconds will ordinarily, by a triple measurement, permit a little closer results than the required one, and one reading to 10 seconds may give the requisite precision with a single measurement, though at least two measurements should be made for a check on the accuracy of the work.

Ordinarily, the position of a point can be more precisely determined by linear than by angular measurement, and, therefore, the former method of determination is in general to be preferred.

CITY SURVEYS

LOT SURVEYS

22. Street Lines.—When, as in the country, a road is a boundary of a farm, the center line of the road is usually the precise boundary; but in the city, the boundary line of property adjoining a street is the side line of a street, known variously as the **property line, building line,** etc. The whole street, including the sidewalks, is the property of the municipality. In some of the older and larger cities, where not only the store buildings but the dwellings have been built on the street line without a dooryard, the local laws provide that a certain portion of the sidewalk area may be used for display windows, stoops and steps, etc., but in many cities the abutting owner is not permitted to encroach so much as 1 inch on the street area. In the western cities of the United States, the street lines have been laid out with much regularity, usually nearly or quite at right angles, and such regularity has often obtained in the later additions to the older cities of the eastern states; but in many of the older cities and towns no regularity prevails; streets are neither straight nor continuous nor of uniform width, and there may very likely be two separate points required to mark the intersection of the center lines of two intersecting streets. The lines usually spoken of with the reference to streets are the *center line*, the *curb line*, and the *property*, *building*, or *house line*. When the term *street line* is used without any qualification, the building line is usually meant.

23. Description of a City Lot.—City lots may be described by the **lot-and-block** or by the **metes-and-bounds** method. By the first method, the lot appears on a map filed for record as a certain parcel of a block bounded

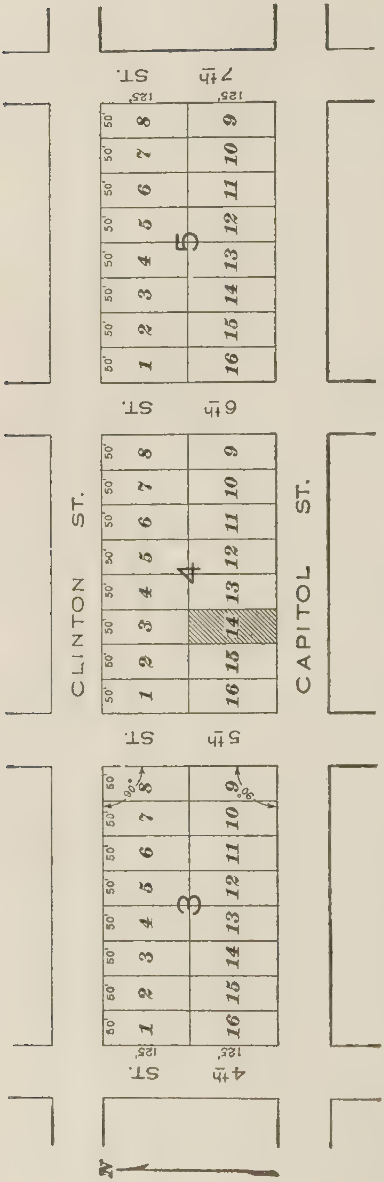


Fig. 4

by streets and designated by a number or letter; the lot also bears a number or letter, and its dimensions are shown on the map. The map bears a title, as, for instance, "Map of Bailey's First Addition to the City of Carthage," or, "Map of the Clermont Tract, City of Waterloo," with some further descriptive matter. Such a map is filed for record in the office of the county recording officer, either the county clerk, the county recorder, or some other officer that may be the custodian of records. The map bears the date of the survey and the date of filing.

Fig. 4 shows a portion of a map of an addition to a city, or a "tract." Supposing it to be the Clermont Tract in the city of Waterloo, filed for record in the office of the recorder of the county of Brown in the state of Ohio, on the 10th day of July, 1896, a description of the shaded lot by lot and block would be as follows:

Lot number 14 of block number 4 of the Clermont

Tract, as the same is shown and delineated on a certain map entitled, "Map of the Clermont Tract in the City of Waterloo" and filed for record in the office of the recorder of the County of Brown, State of Ohio, July 10, 1896.

24. By metes and bounds, the shaded lot in Fig. 4 would be described as follows:

Beginning at a point in the northerly line of Capitol Street, distant thereon easterly 100 feet from the easterly line of 5th Street, and running thence easterly along said northerly line of Capitol Street 50 feet; thence at a right angle northerly (or thence northerly and parallel with the said easterly line of 5th Street) 125 feet; thence at a right angle westerly (or thence westerly and parallel with the said northerly line of Capitol Street) 50 feet; thence at a right angle southerly, 125 feet to the place of beginning.

25. When maps are sufficiently definite, the lot-and-block method of description is to be preferred, particularly with regular subdivisions; since, if a surveyor in attempting to locate the lot measures the block and finds that he disagrees with the recorded length, he will divide the discrepancy among the several lots in locating the desired lot, while if the description is by metes and bounds, he is held rigidly to a beginning point (as 100 feet from the easterly line of 5th Street in Fig. 4), and a surveyor subsequently endeavoring to locate lot *13* from a description, using the westerly line of 4th Street as a basis, may find lot *13* overlapping or falling short of lot *14*, and trouble between owners results, or useless narrow strips are left to make trouble when assessments for street improvements are levied.

26. Encroachment.—Fences and buildings are not always on the lines on which they are supposed to be; they are often built over into the street area, or on adjoining owners' lots or property. These results occur through carelessness in building without a survey, or through the error of some surveyor. When an owner is thus using property, either public or private, that does not belong to him, he is said to be **encroaching.** Many street lines have been

materially altered by succeeding builders following the line of one building incorrectly placed. After erroneous lines have been in existence for many years, it becomes a serious matter to disturb them. They can usually be altered only by agreement between the owners concerned or by order of a court.

27. Statute of Limitations.—What is known as the **statute of limitations** is a state law providing that occupancy and apparent ownership for a certain definite period of time, varying in the different states, shall vest the title to the property in question in the apparent owner; so that, if a bounding fence has been out of place—an owner occupying a few feet or inches of his neighbor's ground—for the specified period of time, the erroneous position of the fence becomes the established position, the occupying owner becomes the real owner of the property in question, and the original owner loses his title to it. Of course, the owners may agree that the fence shall be reestablished in its correct position, and it will require an order of the court to establish the line legally in its erroneous position, but such order usually results from the contested effort of the losing owner to reestablish the disputed line in its correct position. The court will sustain the occupying owner in his contention that the actual or erroneous position of the fence is its correct position, and will so establish it in the records. The possession of such disputed property is called **adverse possession.**

28. Duties of Surveyors Concerning Encroachments.—The first duty of the surveyor with reference to encroachments is to study thoroughly the statute of limitations of the state in which he works. He is then prepared to give advice in any contest that may arise, but he must never, acting for either party, undertake to give a final decision. His position is simply that of an expert adviser whose duty it is to learn where the line should have been, the extent of the encroachment, and the time it has been maintained, and to report his findings with such disinterested advice as may be asked for. When such a boundary line has been finally

established by a court, it in no wise affects other lines that may have been dependent on its original position for their location. They will still be located from the original position of the line, if that position can be determined.

29. **Relocating a City Lot.**—The city surveyor that does lot surveying must be familiar with the monuments and descriptions of the city where he works. He must of course make a beginning without this knowledge, but his earlier work is much the more difficult by reason of his ignorance. His first step should be to familiarize himself with the records and maps of the various parcels of land, and, so far as he can, find from the records the location of the various monuments that have been set. In new cities, these monuments frequently consist only of wooden stakes set at the block corners, with no record of their existence, and the surveyor must be familiar with the customs of those that have preceded him in laying out the subdivisions. When he is called on to survey a lot, he will be furnished with such description as the owner has. This he should verify by referring to such maps of the tract in which the lot lies as may be on record, and to former deeds, which will probably be referred to in the deed of the present owner.

When he has obtained the records that exist concerning the tract, he will go to the nearest monument that he can find, and begin his survey. Just where he will measure—along the property line, the center line of the street, the curb line, or some arbitrary offset line—will depend on the location of the monuments and the existing obstructions. He should, in general, measure through the full length of the block in which the lot lies, to compare his measurements with the recorded measurements; and if the discrepancies he finds are not greater than he would expect in two measurements of the same line at different times by different men, he will distribute the discrepancy through the block in proportion to the recorded frontages of the several lots, making his measurements to locate the lot in question in accordance with such proportional distribution of the discrepancy.

Thus, if he finds that the block is .04 foot longer than the recorded length, and that the beginning point is in the middle of the block, he will make the distance from one corner to that point half of what he finds the length of the whole block to be; and if the beginning point is one-tenth the length of the block from one corner, he will make the distance one-tenth the length of the block as he finds it. In general, where possible, it is more accurate to measure along the front of the lot, establishing points on the side lines from the front line, or from the street line, than to attempt to measure from the end of the block along the front for the front corners and along the back for the back corners.

As an illustration of the methods of procedure, let it be supposed that lot *12*, Fig. 5, is to be located, stakes to be set at the four corners a, b, c, d. Apparently, two methods of locating these four corners are possible; first, locating a and d from the line mp, and b and c from the line st; second, locating all four corners from one of the lines, either mp or st.

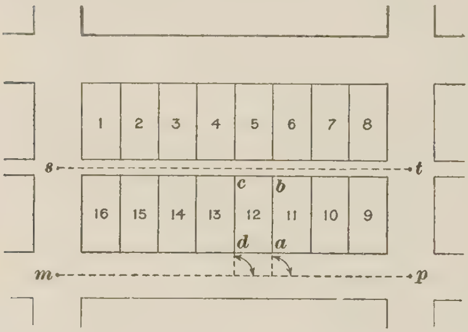


Fig. 5

Thus, by the first method, measurement would be made along the line mp from either m or p to points opposite a and d; the transit would be set over these points and angles turned from the line mp to a and d, respectively, and the offset distances from the line mp measured. The same procedure, using line st, would locate c and b. By the second method, using, for example, the line mp, measurement would be made as before to points opposite a and d, the transit set on these points, the proper angles turned from the line mp and measurements made to a and b, and d and c, respectively.

It is probable that the location of *b* and *c* will be rather better by the second than by the first method, and it is practically certain that it would be better if there are no monuments at *s* and *t*, as is the usual condition, necessitating, if the first method is used, measurements from *p* and *m* to the line of the alley, and measurements along the alley to locate *c* and *b*. If there are monuments at *s* and *t*, the first method may be as precise as the second, and if there are obstructions on the lines *a b* and *c d*, it will almost certainly be the better method.

30. The lot corners may be marked by stakes with tacks for temporary marks, or by stone monuments or iron pins if the corners are not to be occupied by a building or fence. Iron pins or stone monuments may be set in the sidewalk area on the extension of the side lines, or crow's-foot (↓) marks may be made in the curb. The permanent marking of the back corners is not generally required. Stakes with tacks usually answer the purpose, or marks may be made in the alley curb or paving.

31. When the discrepancies in the measurement of the whole block prove too large, and correct measurements in agreement with the description are in conflict with adjoining lines already located, the surveyor should report what he finds, after assuring himself that his own work is correct, and ask for further instructions, unless he is familiar with local practice in connection with these discrepancies. He should remember that he has no power to determine where a line must be; he can only give his judgment as to where it should be, leaving a court to decide where it shall be, in case the adjoining owners do not agree.

32. Certificate and Plot of Survey.—The result of a survey of a lot should be reported to the owner in somewhat the following form, blanks for which may be printed, leaving a space for drawing the map, and requiring only the name of the owner, the date, and the signature of the surveyor.

CERTIFICATE OF SURVEY

HABBERTON, OHIO,__________190__

I hereby certify that I have this day made a survey of the premises described as *Lot 26, Block 4, Turner's Addition to the City of Habberton,*

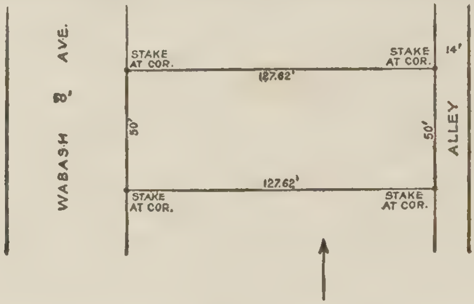


FIG. 6

and that I have found the lines and marked them as shown on the subjoined plot.

Survey made for____________________

at request of____________________

____

SURVEYOR

When, for building design and computations, the architect desires a complete survey, it is necessary to add to the data given in the ordinary lot certificate. The following items should appear on the plot:

1. Lines of the lot, with dimensions and angles in figures, and curb lines.
2. Grade of street, actual and established, and of the alley, if there is one.
3. Location, elevation, and size of sewer, with elevation of its flow line.
4. Location and size of gas and water mains.
5. Elevations at the corners of the lot, and more frequently if the ground is not flat. In this case, the lot may be divided into small squares and elevations taken at the corners and elsewhere if necessary.
6. All trees, if any.
7. The lines of adjoining buildings, with elevations of their floor levels.

8. Character of soil, whether rocky or underlaid with rock within a depth likely to be reached by the cellar excavations.

Fig. 7 is a lot map showing some of these details; all dimensions are supposed to be in feet. The figures in marks of parenthesis express elevations above an assumed datum.

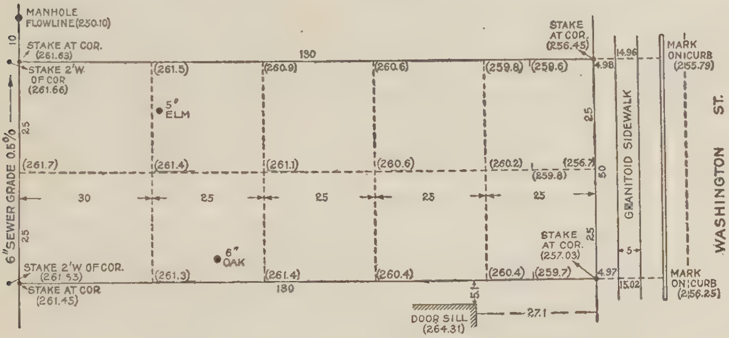


FIG. 7

If a building covers the lot, its outlines should be indicated with fine shading inside the lines, as shown in Fig. 8.

The certificate of survey should be on a piece of tracing cloth or tough linen tracing paper, cut to the size of a deed

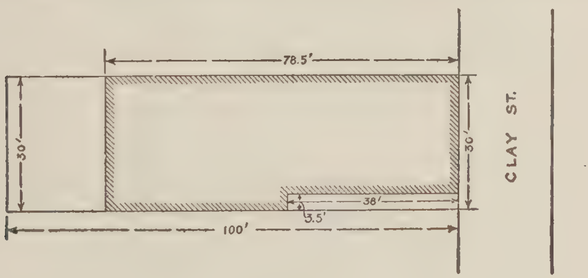


FIG. 8

blank, or legal cap. One or more prints from the tracing are filed for office use, the original being given to the client. The certificate may be folded like any legal document, and filed in a document filing case.

SUBDIVISIONAL SURVEYS

STREETS AND BLOCKS

33. General Street Plan.—The engineer is seldom called on to lay out a new town site likely to be covered by a large city, but occasionally this task comes to him, and he is frequently asked to plan and lay out additions to existing towns. In many respects, the principles governing the design of a street plan for a new town apply to the planning of a new addition. Some of these principles are here given.

A business district of comparatively small blocks and fairly wide streets should be surrounded with a residence area of larger blocks, generally large enough to make two business blocks with an intermediate street as the business district grows. The blocks should be rectangular, giving streets at right angles, about twice as long as wide, with directions such that a maximum of sunlight may reach streets and buildings. These directions may vary with the latitude, but in the temperate zone they should in general be diagonal with the cardinal points, that is, northeast and southwest and southeast and northwest. Streets thus laid out will all have sunlight for a considerable portion of each sunny day, though none of them will receive the noon rays. All four sides of every block will receive sunlight at some hour of every sunny day.

Radiating from the business district in at least four directions, north, south, east, and west, should be diagonal avenues of considerable width. These avenues, together with the rectangular streets, provide the shortest practical routes to the different parts of the city. At intervals of perhaps $\frac{1}{2}$ mile, there should be cross-avenues about at right angles to these diagonal avenues, and at the intersections of the two sets of avenues there should be park places of one or more blocks. Much of the direction of the streets may depend on the topography. The plan should be such as to secure reasonable grades, with no impassably steep hills,

with good drainage toward the streets and toward one or more main drainage lines serving as outlets for the drainage of the city.

34. Street Plan of the City of Washington.—The nearest approach in America to an application of these principles is the city of Washington. The plan of the city was originated by Major L'Enfant, a young officer of the engineering corps of the French army that aided the United

FIG. 9

States in its Revolutionary struggle. The plan was approved by President Washington, and laid out on the ground about 1791 by Andrew Ellicott; it has proved entirely adequate to the more than a century's development of a large and beautiful city.

Fig. 9 shows a portion of this plan. The main subdivision is rectangular, with streets extending north and south and east and west, intersected by numerous diagonal avenues,

providing fairly direct routes between any two portions of the city. From the center of the Capitol, the streets extending east and west are named in order A, B, C, etc., north and south, while those extending north and south are named in order First, Second, Third, etc., east and west, and the diagonal avenues are given the names of different states. The irregular, inconvenient, and inadequate streets shown at the left of the figure are the result of individual liberty in the laying out of additions. This liberty was somewhat tardily curtailed by legislative authority, and future additions must conform to the general plan of the city.

35. Size of Blocks.—A block may be any length not too great for the convenience of travel; about 480 feet from center to center of streets is a good length, though 660 and 400 feet are not uncommon lengths. The width will be the depth of two lots, or two lots plus the width of an alley, if there are alleys. Lot frontages may be anything desired; they are most frequently from 20 feet to 25 feet in business and congested residence districts in large cities, and from 50 to 150 feet in villages and small towns. They are usually an aliquot part of the net block length. The depth may be 100 feet in business and residence districts of large cities, and from 100 to 160 feet in villages and small towns not likely to grow large. Frontages and depths vary much with the ideas of the owners of property, and with the size of the tract; thus, there are residence lots 125 feet front by 60 feet deep—very awkward dimensions. For residence districts, lots should be of such width—unless they are of minimum width—that they will divide into a whole number of business lots of equal width; thus, a 50-foot lot will divide into two 25-foot lots; a 40-foot lot into two twenties; an 80-foot lot into four twenties, etc.; but a 35-foot lot is too large for a small business property, and too small for two business lots.

36. Widths of Streets.—Streets should be wide enough, from property line to property line, to accommodate travel. and to permit the entrance of sunlight and air to the buildings on both sides. Principal business streets in large cities,

like New York, Chicago, Philadelphia, and St. Louis, should be 200 feet or more in width. Boulevards for driving, with a parkway through the middle, should be of a like width. Less important business streets may be 100 feet wide, and minor streets 80 feet. Residence streets should be not less than 60 feet—a common width—and need not be more than 80 feet in width. If street-car tracks are likely ever to be laid, even minor streets should be not less than 100 feet wide. The streets of most old cities are too narrow for convenience of travel, or for the entrance of light and air. This is partly due to the unforeseen growth of small villages; partly to the desire of owners to make the largest number of lots from their property; partly to the unforeseen increase in modern transportation lines; and partly to the fact that the necessity for light and air was not formerly so thoroughly appreciated as now.

37. Widths in the City of Washington.—In the city of Washington, the streets are generally 70, 80, 90, 100, and 110 feet in width, though one important street is 160 feet wide, and one short, unimportant street is only 40 feet wide. The avenues are generally 160 feet wide, though a few have widths of 130, 120, and 85 feet. The law now requires that, in laying out new streets and avenues, the width shall not be less than 90 feet for streets nor less than 120 feet for avenues. Intermediate streets, called **places**, may be laid out within blocks with a width of 60 feet, but the distance between full-width streets must not be more than 600 feet. Washington probably has the best and most liberal system of streets in America. The beneficial results of its liberal policy with regard to streets are evidenced by its large growth, by its popularity as a residence city, by the corresponding increase of property values, and by the great comfort enjoyed by its inhabitants.

38. Alleys.—Where laid out, alleys should be about 20 feet wide. Opinions vary as to the desirability of alleys. The argument for them is that they provide convenient access to residence and business property for the delivery of

materials and the removal of refuse, and afford convenient locations for sewers. The argument against them is that they are likely to become foul and unwholesome through neglect. Under properly enforced adequate regulations, alleys may be a convenience, but cases of such adequate control are so few that the weight of evidence is very much against the alley.

THE WORK OF SUBDIVISION

39. Preliminary Survey.—When a tract of land within or adjoining a city is to be subdivided into building lots, the first step of the surveyor is to look it over with the owner to decide what sort of subdivision shall be made, and the second step is to make an outline survey of the tract with a high degree of precision. It will doubtless be found that the new precise survey will differ from the former surveys made when the property was farm land; but, if the real boundaries can be found, the difference will be of no consequence, as a map of the subdivision, with the new and presumably correct dimensions, will be filed. The survey should be carefully balanced by the methods explained in *Transit Surveying*, Part 1, the angular work being so done in the field that it will close with an error not greater than the smallest reading of the transit.

The boundary survey should include the determination of the points of intersection of the lines of all existing streets that if produced would enter or cross the property, and the directions of those street lines. The work should be done by the usual method of traversing with the transit, using azimuths rather than bearings or deflection angles. The boundary survey should be plotted to a large scale by the method of latitudes and longitudes, the latitude and longitude of each corner from some arbitrary meridian and base, or from an established local meridian and base, being determined. If the tract is reasonably level and small, no topographical survey will be required; but if it is large and undulating, a topographical survey should be made with sufficient precision to permit drawing 2-foot contours with

some degree of accuracy. If the tract has any large trees, they should be located, so that they may be preserved if possible.

40. Planning the Subdivision of a Small Tract. If the tract is small—say, a block or so—surrounded by or adjoining the previously subdivided portions of the city, there is but one thing to do, and that is, to extend the intersecting streets through the property, unless such extension would work serious harm to it. In some cities, as Washington, ordinances provide that all new subdivisions must conform to the surrounding subdivisions. When the property of adjoining owners does not permit of such subdivision without leaving small fractional gore-shaped lots, transfers between the owners may frequently be made with advantage.

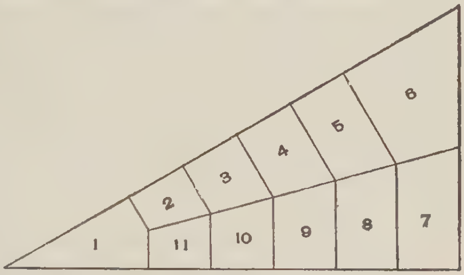


FIG. 10

After the boundary survey has been made, the outline is mapped to a large scale, the streets are drawn in, and the resulting blocks subdivided into lots of such size as may seem desirable. The distances must not be scaled from the map, but must be obtained by direct measurement in the field, or by computation from such measurements and the measured angles. If the blocks are irregular, a scheme of subdivision should be adopted that will, as far as possible, produce parallel side lines at right angles to the front, leaving irregularities at the back line; and when it seems impossible to bring the side lines at righ'

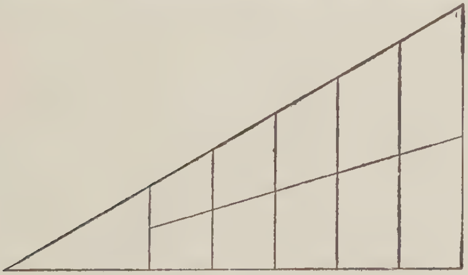


FIG. 11

angles to the front, they should still be kept parallel. Thus, the divisions of the two blocks shown in Figs. 10 to 13

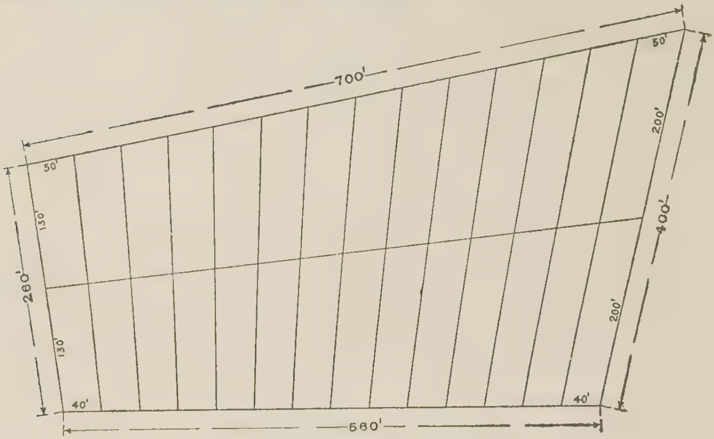


FIG. 12

should be as indicated in Figs. 10 and 13 rather than as shown in Figs. 11 and 12.

The dividing line at the back of the lots bisects the angle between the front lines. The irregular dimensions are all

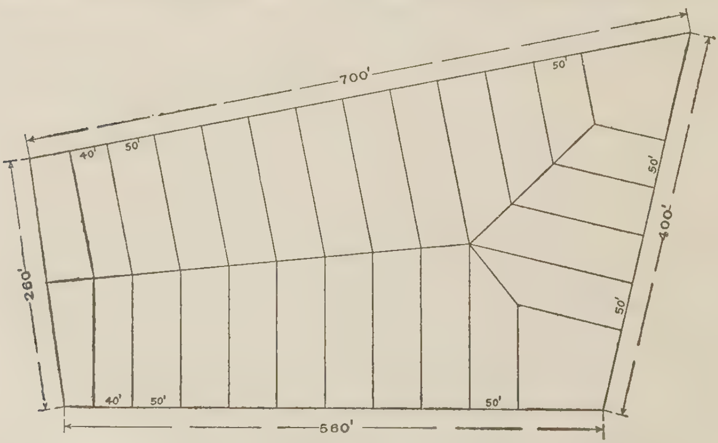


FIG. 13

thrown into the corner lots. The side lines of the lots on the two streets should meet at the back, so that lots may be

purchased through from street to street without offsets in them. Where alleys extend through the block, this is of course unnecessary.

In general, where blocks are rectangular, it is unwise to face the lots on more than two streets, as, if they are faced on three or four streets, there result what are known as **key lots**, that is, lots against whose sides lie the backs of other lots. In very large cities, the frontage value in business and even residence districts becomes so great that this rule is ignored.

Permanent monuments should be placed marking the block corners or street lines, in accordance with the customs or ordinances prevailing in the city. A map should be made showing the subdivision, the block and lot numbers, the streets, every dimension and angle necessary to relocate or determine any lot, the positions of all monuments placed and a description of those monuments, and such witness points as may be known, sufficient to enable another surveyor to find them. The title of the tract, the date of the survey, the scale of the map—both drawn and written—and the name of the surveyor should all appear on the map.

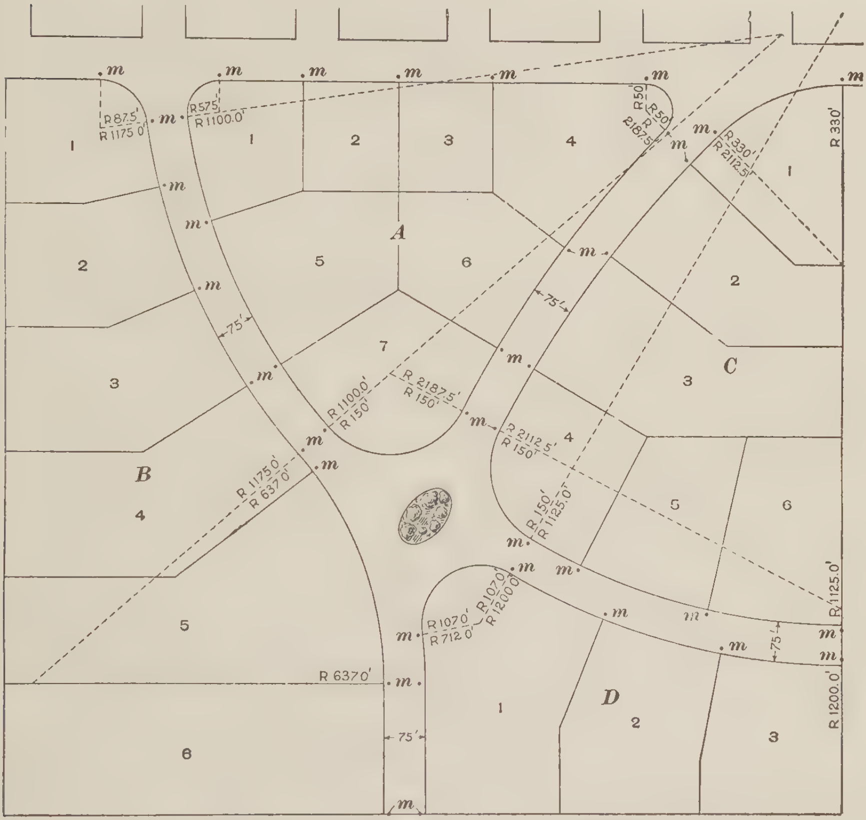
41. Planning the Subdivision of a Large Tract. If the tract is a large one, either within or without the previously subdivided city, and if the territory is fairly level, the surrounding or nearest street lines should be produced through the property; the work of subdivision is then essentially the same as that for a small tract. If, however, the ground is rolling, well out from the city, and almost certain for many years to be residence property, an irregular subdivision may be planned. This is a somewhat dangerous proceeding, especially if the tract is situated within any reasonable distance of a large and growing city, but is rather desirable in the case of a tract that is situated on the outskirts of a small town likely always to remain small or is at some distance from a large city. In this case, the subdivision will be based on the topography of the tract and on the character of residences desired. After the boundary

survey is finished, a careful topographical survey should be made by transit and stadia, by plane table, or by dividing the tract into parallelograms and using a wye level, as explained in *Topographical Surveying*. A contour map is made, preferably with contour intervals of not more than 2 feet, and on this map the streets and lots are plotted. In general, the streets should take the valley lines; there should be no angles, but easy graceful curves, and for a tract to be offered to well-to-do residents the lots should be large—none perhaps less than 1 acre in extent. If the tract is to be offered to persons of small means, the lots must be smaller; and when this is the case, the more closely the subdivision approaches a rectangular plan, the better.

42. In laying out curved streets, the curves should be arcs of circles, those of different radii joining with common tangents as compound railroad curves. At all changes of curvature, there should be referenced monuments set on the arcs or at uniform offsets from them on the radial lines produced. Long-radius curves should be used, except at street intersections, where the corners will be rounded with short radii. It is not usual to introduce alleys in curved subdivisions. To be entirely successful in laying out park-like subdivisions, a surveyor must have an artist's eye and some training in the principles of landscape architecture.

43. The general plan is first studied on the ground, then on the map, and a plan worked out on the map is again studied on the ground, to see that the property has been developed to the best advantage. The main streets are placed in the valley lines to insure easy and complete drainage, and to leave the more sightly hills for dwellings. After the plan has been finally determined, a finished map is made, the block and lot monuments are set, and the work is complete so far as the subdivision is concerned. As owners of such tracts frequently desire to grade the streets, lay sewers, water and gas mains, and sidewalks, the surveyor's work may include the staking out and supervision of such work, and the estimate of quantities. It is usually desirable to

make these improvements before placing the property on the market, since the increased selling value of the property is almost always considerably in excess of the cost of the improvements.



OUTLINE MAP OF CLERMONT PARK, showing Position of Monuments.—
m = Monument.–4 ft. from Property Line.

FIG. 14

44. Fig. 14 will illustrate the foregoing description concerning curves and the positions of monuments. As far as possible, it is well, as indicated in the figure, to have all division lines radial that run back from the street lines. In

this subdivision, the division lines on the left of the tract are made perpendicular to the left outside boundary, to provide for the possible future opening of a street along that boundary line, and for the division of the frontage into smaller units. A finished map of such a tract should show all dimensions and angles, and it should be made to a scale large enough to permit these data to be given without confusion. The accurate computation of the lines and areas of such a tract is a very tedious operation, and the dimensions are more frequently than otherwise obtained by scaling from a large map, the areas being found by the use of the planimeter.

45. The Map.—Whether the tract is large or small, the map should be a complete and faithful record of the subdivision in every particular. A great many very imperfect maps have been made and filed—maps that are mere pictures and fail to give the data necessary for the description or relocation of the various parcels shown. A map that is to serve as a basis for descriptions of property in transfers and for the location of the parcels transferred should contain two sets of data—one for the description and location, and one to insure the reliability of the data shown.

The first set of data should include:

1. The lengths of all lines shown.
2. The exact angle made by all intersecting lines.
3. The exact position and character of all monuments set, with notes of reference points.
4. The number of each block and lot.
5. The names of all streets, streams, or bodies of water, and recognized landmarks.
6. The scale.
7. The direction of the meridian, and a note as to whether the true or the magnetic meridian is shown. (It should be the true meridian.)
8. The angles made by the lines of adjoining property with the boundaries of the tract mapped.
9. A simple, complete, and explicit title, including the name of the surveyor, and the date.

The second set of data contained in the map should include:

1. The certificate of the surveyor that he has carefully surveyed the land, that the map is a correct representation of the tract, and that he has set monuments (to be described) at the points indicated on the map.

2. The acknowledged signature of all persons possessing title to any of the land shown in the tract, and, if possible, signatures of adjoining owners.

3. If of an addition, the acknowledged dedication to public use forever of all areas shown as streets, roads, or other public areas.

4. If a street of full width whose center line is a boundary of the tract is shown, the acknowledged signature of the owner of the adjoining property to his dedication of his half of the street, unless that half has been previously dedicated.

GRADING SURVEYS

46. Levels and Profiles.—Surveys for grade, either for street-surface grades or for sewer grades, consist simply in leveling and making profiles. For sewers, levels along the center lines of the streets will suffice, with now and then for every block an observation of the depth of cellar, that is, the elevation of the bottoms of the deepest cellars to be drained. In some great business buildings in very large cities, there are basements and subbasements below the level of the street sewers, and these must be drained by some form of pumping or ejecting plant; but, in ordinary cases, the sewers must be placed deep enough to drain the deepest cellars.

47. For street-surface grades, the levels should be taken as often as once in 100 feet—oftener if the changes in surface grade make closer points desirable—and at all street intersections. Three lines should be leveled on each street—the center line and the two block, or property, lines—and these should be plotted on one profile map in three different colors to distinguish them. If the street is level across, or essentially so, as is the case in some western cities of the United

States, elevations of the center lines will be sufficient. Perhaps the best scale for the profile is 100 feet to the inch for horizontal measurement, and 10 feet to the inch for vertical measurement; this scale fits cross-section paper ruled to inches and tenths. Cross-section paper is better than profile paper for street-grade profiles.

48. Setting Grade Stakes.—Grade and line stakes are set for all street grading and sewer construction, and sometimes, though not so generally, for water mains, gas mains, electric conduits, etc. Stakes set for street grading are placed at the edges of the excavation or embankment on the property or block line, and marked with the cut or fill needed to bring the points, when they are set, to grade. If the depth of the cut or fill is not too great, the top of the stake is driven to the grade elevation, or "to grade," excavating a little where necessary, or using a long stake for embankments; the stake, or a guard stake, is marked "grade." When the work nears completion, stakes centered with tacks are set for the curb lines and grade at intervals of 50 feet.

49. Trench stakes for sewers must give the line and grade. Perhaps the most convenient method is to set the stake about 2 feet from the edge of the trench at the foot of the pile of excavated earth, which will begin about that distance back from the edge. The face of the stake next the trench should be driven exactly to a definite offset from the center line of the pipe or sewer, and the top of it to a definite whole foot (where convenient) above the grade of the trench. By using an arm containing a small bubble, and a rod to slide through one end of the arm, the foreman, having a

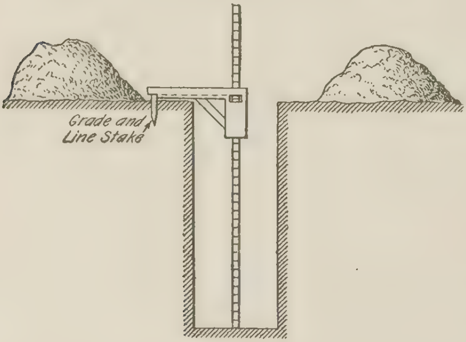


FIG. 15

record of the depth of grade below the stake, can finish his excavation to true surface without calling on the surveyor.

Fig. 15 illustrates the method just described. The distance from the shoulder on the arm that rests against the face of the stake to the center of the slot through which the rod slides, and hence to the center of the rod, is made equal to the length of the offset of the stake from the center line of the trench. A different arm may be provided for different offsets used with trenches of different widths, or an adjustable arm may be used. The bracket arm is built in to form a right angle. A small carpenter's level may be fastened to the top of the arm.

When the banks are of shelving earth, sheet piling is used, and the stakes, if placed too near the trench, are likely to be disturbed; they are then set farther away, and the line and grade of the trench must be given by the surveyor.

50. Surveys for Lot Grading.—When a lot or block is to be graded to a definite surface, and the volume of earth moved is to be computed, the usual method of procedure is as follows (see Fig. 16): The lot is divided into squares or rectangles so small that the surface of each rectangle or square may be considered plane. Stakes p are set in line with the subdivision lines, as shown outside of the block, in such positions that they will not be disturbed by the grading operations. The sides are numbered one way and lettered the other way. Any corner is designated by the letter and number of the lines intersecting at it, the number being attached to the letter as a subscript. Thus,

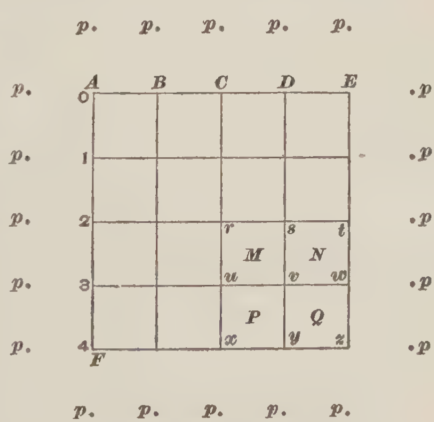


Fig. 16

the corner u is called C_3. The elevations of all the corners are determined next. The difference between the elevations before and after grading will be the depths of cut or fill at the several corners. The corners may be located on the ground after the grading, by lining from the stakes set outside the block.

51. Computation of Volumes.—Each rectangle shown in Fig. 16 is really the horizontal projection of the area included between the four stakes. When the soil is excavated to the required grade, the volume excavated is part of a prism cut at one end by the natural surface of the ground, and at the other by the grade surface. The horizontal projection of such prism (the corresponding rectangle shown in Fig. 16) is called the **right section** of the prism. The edges of the prism are the differences in elevation between the four corners on the natural surface of the ground and the corresponding corners of the graded surface. With the necessary change of terms, what has been said of excavation applies to fills.

The volume of each prism can be obtained by multiplying the area of its right section by the mean of the lengths of its four edges. The computation of the volume may be simplified by applying a formula that gives the sum of all the prisms. To show the application of the formula, let the four prisms whose right sections are M, N, P, Q be considered. If K represents the area of each rectangle, and the depth of cut or fill at a corner is represented by the letter at that corner, then, denoting the volumes by V_m, V_n, etc., we have

$$V_m = \frac{K(r+s+u+v)}{4}$$

$$V_n = \frac{K(s+t+v+w)}{4}$$

$$V_p = \frac{K(u+v+x+y)}{4}$$

$$V_q = \frac{K(v+w+y+z)}{4}$$

Adding, we have for the volume V_4 of the four prisms,

$$V_4 = \frac{K(r + 2s + 2u + 4v + t + 2w + x + 2y + z)}{4};$$

or, in cubic yards,

$$V_4 = \frac{K}{4 \times 27}[(r + t + x + z) + 2(s + u + w + y) + 4v]$$

The first parenthesis is the sum of all the corners used but once, or for but one prism; the second is the sum of all those used twice, or belonging to two prisms; while the v that is multiplied by 4 is the one height that belongs to all four prisms. If there had been a height belonging to three prisms—if, for instance, the prism Q had not been included—the height v would have been used three times, and hence multiplied by 3. From these considerations is derived the following general rule for computing the material excavated:

Rule.—*Add all the heights, in feet, belonging to a single prism, twice the sum of those belonging to two prisms, three times the sum of those belonging to three prisms, and four times the sum of those belonging to four prisms; multiply the sum by the area, in square feet, of one rectangle or right section, and divide the product by 4 × 27 to obtain the volume in cubic yards.*

This rule is general and gives the amount of *excavation*, in case all the corners are above grade. If all the corners are below grade, the result is the amount of *fill*. When some of the corners are above and some below grade, the heights of those below grade are considered negative, and the result is the amount of material *removed*, or the *difference* between the cut and the fill. If the result is positive, it shows that the cut is in excess, and, if negative, that the fill exceeds the cut. In estimating the cost, it is necessary to know both the cut and the fill; therefore, it is necessary to calculate one of these values separately, and, from it and the results obtained by the formula, to determine the other value. The method of procedure is illustrated by an example to be given presently.

In the lot represented in Fig. 16, the corners A, E, z, F would be used only once; each of the other outside corners, twice; and each of the interior corners, four times. No corner would be used three times.

EXAMPLE.—In the rectangular block shown in Fig. 17, the elevations found at the several corners are as follows:

A_0, 105.6	B_0, 104.0	C_0, 102.8
A_1, 103.8	B_1, 102.4	C_1, 101.5
A_2, 102.7	B_2, 101.6	C_2, 98.3
A_3, 100.8	B_3, 99.4	C_3, 97.2

It is desired to grade the block to a level surface of elevation 100. How much is utilized in filling the low portion, and how much is to be wasted or hauled away?

SOLUTION.—An inspection of the elevation shows that the surface is a rounded hillside sloping from the upper left corner A_0 toward the lower right corner C_3, and that the lower right portion must be raised or filled to bring it to elevation 100, while the greater part of the block must be lowered or cut. Between the portion to be filled and that to be cut there will be a line, more or less irregular, that will be just at elevation 100, and hence a grade line, or line of no cut or fill. An inspection of the corner elevations shows that this line will cut the C line between C_1 and C_2, the *2* line between 2_B and 2_C; the B line between B_2 and B_3, and the *3* line between 3_A and 3_B. To find the volume it will be necessary to determine just where this grade line crosses the sides of the several rectangles.

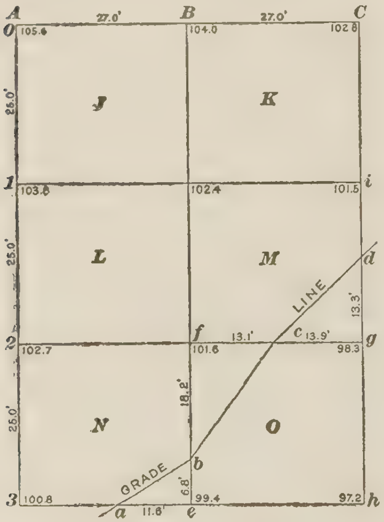


FIG. 17

Assuming that the slope is uniform from one corner to the next, the ground rises 3.2 ft. from g to i; hence d, elevation 100, or 1.7 ft. above g, will be $\frac{1.7}{3.2}$ of 25 ft., or 13.3 ft., from g toward i. Similarly, gc is found to be 13.9; fc, 13.1; fb, 18.2; be, 6.8; and ae, 11.6—all figured to the nearest tenth of a foot. First the amount wasted or

hauled away will be determined by applying the rule given in this article. The heights used but once are:

$$\begin{array}{lrr} A_0 = & +\ 5.6 & \\ A_3 = & +\ \ .8 & \\ C_3 = & & -2.8 \\ C_0 = & +\ 2.8 & \\ \hline & +\ 9.2 & -2.8 = \end{array} \qquad +6.4$$

The heights used twice are:

$$\begin{array}{lrr} A_1 = & +\ 3.8 & \\ A_2 = & +\ 2.7 & \\ C_1 = & +\ 1.5 & \\ C_2 = & & -1.7 \\ B_0 = & +\ 4.0 & \\ B_3 = & & -\ .6 \\ \hline \end{array}$$

$$(+\,12.0 - 2.3) \times 2 = +9.7 \times 2 = +19.4$$

The heights used four times are:

$$\begin{array}{lr} B_1 = & +\ 2.4 \\ B_2 = & +\ 1.6 \\ \hline & +\ 4.0 \times 4 = \end{array} \qquad \begin{array}{r} +16.0 \\ \hline +41.8 \end{array}$$

The volume of waste is

$$\frac{25 \times 27 \times 41.8}{4 \times 27} = 261.3 \text{ cu. yd.} \quad \text{Ans.}$$

The volume of the triangular prism of fill $c\,d\,g$ is

$$\frac{13.3 \times 13.9 \times 1.7}{2 \times 3 \times 27} = 1.9 \text{ cu. yd.}$$

Similarly, the volume of the triangular prism of fill $a\,b\,e$ is

$$\frac{6.8 \times 11.6 \times .6}{2 \times 3 \times 27} = .3 \text{ cu. yd.}$$

The difference between the cut and the fill on the rectangle O is

$$\frac{25 \times 27}{4 \times 27}(1.6 - .6 - 2.8 - 1.7) = -21.9 \text{ cu. yd.}$$

The negative value shows that the fill exceeds the cut.

The cut in the triangular prism $f\,b\,c$ is

$$\frac{18.2 \times 13.1 \times 1.6}{2 \times 3 \times 27} = 2.4 \text{ cu. yd.}$$

In the rectangle O we have $F - C = 21.9$, and $C = 2.4$; whence $F = 21.9 + 2.4 = 24.3$ cu. yd. The total fill for the entire tract is

$$1.9 + .3 + 24.3 = 26.5 \text{ cu. yd.} \quad \text{Ans.}$$

52. Quantities in Street Grading.—The earthwork to be moved in street grading is usually best measured by

taking cross-sections of the street as often as needed, determining the areas of those sections, and applying either the prismoidal formula or the average end-area method. The street cross-profile will be a standard form, such as is shown

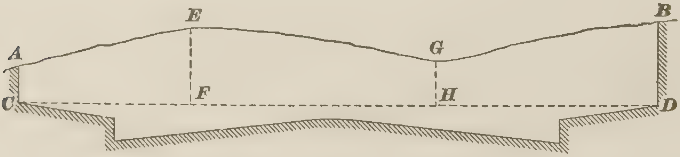


FIG. 18

in Fig. 18; the area below the line CD, which will be common to all sections, may be computed once for all, the area remaining to be computed being $ACFHDBGEA$. In the field, levels would be taken at A, E, G, and B, from which, and the known grade elevations, the heights AC, EF, GH, and BD could be obtained. Some engineers advocate the use of the planimeter for computing the area, but it is doubtful whether this is wise—unless the sections must be carefully plotted to scale for some other reason—as the computations can be made almost if not quite in the time taken to plot the sections. The trapezoidal rule or Simpson's rule can be used for these computations (see *Plane Trigonometry*,

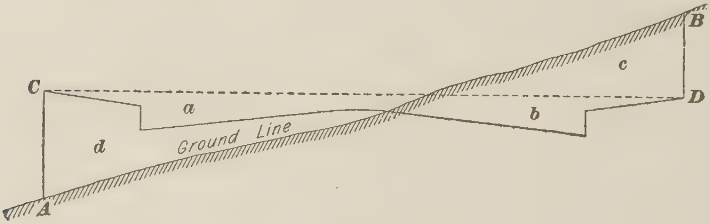


FIG. 19

Part 2). In side-hill work (see Fig. 19), it may be best to use the planimeter, measuring the cut and fill areas separately. The volume is calculated as explained in *Earthwork*.

MONUMENTS AND BENCH MARKS

MONUMENTS

53. Purpose of Monuments.—Monuments in a city may be for one of two purposes; namely, the determination of elevations, or the location of lines. Those used for elevations are called **bench marks**, and those used for the location of lines, simply **monuments.**

54. Necessity for Line Monuments.—That permanent monuments to mark the street or block lines in a city are an absolute necessity seems almost to go without saying; yet, in almost all cities, the original marks defining the street or block lines have long since disappeared, and the lines have been perpetuated by buildings supposed to have been placed on the lines. Had the buildings been so placed, the destruction of the monuments would not have been so serious a matter, but, as a rule, they have not been correctly placed. Often the best that can be done is to average up the lines indicated by various buildings or fences known to have been intended to be on the lines sought. In many of the older larger cities, these lines have become well fixed by the years of repeated locations, but in many newer cities and additions the practice is still to place a wooden stake at the block corners, to be removed when the fence posts or the building is begun. It would be an exceedingly wise thing for every city to have permanent monuments set to mark every street line now unmonumented, and to require the setting of such monuments in all new tracts in which streets are offered to the public. If permanent indestructible monuments do not exist, each surveyor, in his endeavor to arrive at the truth, will interpret the existing lines according to his knowledge, in all probability choosing, as most correctly representing the lines, buildings or fences different from those taken by his predecessors, with the result that the offsets and irregularities frequently lead to costly litigation.

55. Materials for Monuments.—Wooden stakes have been most generally used for the first monuments of a subdivided tract. They last a few years, perhaps five in good soil, and longer when made of cedar or redwood; they are cheap, and easily centered with a tack; but they are also easily moved by the action of frost, and are altogether unsuitable for permanent monuments. Iron pins have been much used and serve very well for a few years; but are also easily disturbed by frost, and in a country with cold winters do not make good permanent monuments. Iron monuments are easily found by using a magnetic-compass needle in the immediate vicinity of the pin. They last many years longer if of cast iron than if of wrought iron.

Satisfactory monuments have been made of fireclay, or shale, 2 feet long and 4 inches in diameter. An excellent monument is made by boring with a post-hole auger about 2 to 4 feet into the ground and filling the hole with cement mortar composed of from two parts of sand to one of cement to four of sand to one of cement. The monument may be centered while yet soft by placing in it at the proper point a copper bolt whose head contains a graven or stamped cross.

Probably the best monument is one of granite, about 6 inches square on top, larger at the bottom than at the top, dressed down from the top on four sides for about 6 inches, with a copper bolt set and leaded into a hole drilled in the top. The stone should be 3 or more feet long, and should be set below the depth of frost. A temporary gas pipe or other tube may reach from the mark on the top of the monument to the surface of the ground, or a cast-iron box similar to a manhole cover may be used to keep a space open to the stone.

A crow's-foot mark on a curb is often used as a monument. This is a very cheap and convenient form of monument, but is likely to be disturbed in repairing the street or sidewalk, and may even be removed with the curbstone.

56. Position of Line Monuments.—Three general positions are chosen for line monuments; namely, (1) the

intersection of street center lines; (2) the block corners; (3) a point at some arbitrary distance from either the center lines or the property lines. The difficulty with the center-line intersection is that sewers are usually in the center of the street, and necessitate deep openings that disturb the monument. Water and gas pipes and steam and electric conduits lie on each side of the center of the street, buildings occupy the block corner, and in the business district the areas under the sidewalks are used for vaults, coal bins, etc. Paving operations covering the entire street, street-car tracks and conduits, and other constructions make it almost impossible to find a permanent spot for a monument. It is probable that, in residence districts, monuments set at small offsets, 1½ to 5 feet from the property lines, are most favorably located; while, in business districts, perhaps the best monument is a mark on the curb. It will be disturbed, to be sure, from time to time, but not frequently, and if properly protected by ordinance, and properly referenced, it can always be recovered with ease, and it is in the least obstructed part of the street area in a large and busy city. The mark should be placed at an offset from the property lines, as shown at *m* in Fig. 20, to permit ranging with the transit. The offset should be uniform throughout the city.

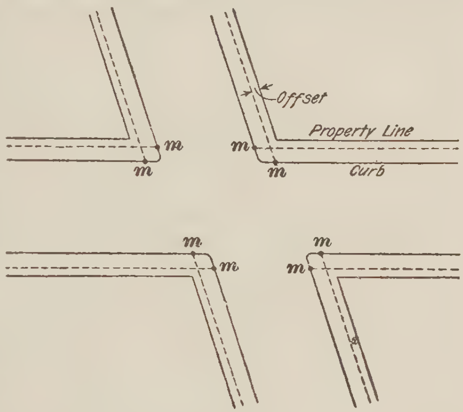


FIG. 20

57. Witnessing of Monuments.—All monuments should be *witnessed* by making and recording measurements to near-by objects of reasonable permanence. While the monuments are supposed to be permanent, they may be

disturbed, and, being sometimes covered, the witness measurements assist in finding them. A sufficient number of witnesses should be secured to allow for the destruction of one or more. If permanent objects do not exist near a monument, auxiliary monuments may be set above the ground, and measurements taken to them. Such monuments are called **witness monuments.** The measurements are not usually made with sufficient precision to relocate the exact center point of the monument, and hence are not reliable for replacing exactly an obliterated or lost monument. They should, however, be sufficiently accurate to relocate from witness points the monument close to its former position. When a monument is to be disturbed for street improvements, it should be *exactly* referenced, preferably by cross-lines to temporary points not to be disturbed during the improvements, and replaced as soon as the ground will permit. If the reference points can be set close to the monument, the best way is to stretch two fine strings across the monument, with their intersection on or over the center of the monument and their ends on the witness points selected. If the witness points must be at some distance—say 25 or 30 feet or more—the transit may be set over one witness point, ranged on the monument, and a second witness set in this line produced; the transit will then be set on a third witness to one side of the line just ranged, turned on the monument, and a fourth point set in the line prolonged. After the work that has disturbed the monument is complete and the ground has been properly settled, a reversal of the operation will fix the monument again. The method is to set on the first witness point, range on the second, and set two points close to and on opposite sides of the approximately known position of the monument; then, stretching a string over these two points, set the transit on the third point, range on the fourth, and find a point in this line on the string. This will be the center of the disturbed monument.

BENCH MARKS

58. Character and Location of Bench Marks. Bench marks are permanent objects—such as points on the water-table or other projection of permanent buildings—whose elevations above a plane or surface, known as the **city base, city datum,** or simply **the base,** are known. The elevations are determined by leveling from a primary bench mark, whose elevation above the city datum may either be obtained by leveling, if that datum is a natural existing surface, as mean sea level, or be assumed, if the datum or base is an arbitrary surface considered as being so many hundred feet below the primary bench mark. The latter condition usually obtains in inland towns, although efforts are frequently made to have the base approximate the level of the sea, assuming the primary bench mark to be the round hundred of feet nearest to its supposed or known elevation above sea level. In cities on the coast, it is usually desirable to have the city base below mean tide, perhaps 100 feet, in order that elevations taken in excavations that may extend below tide water may not be negative.

The bench marks for a city should be well distributed, so that leveling operations for grading or building in any part of the city may start from a near-by bench mark. They should all be consistent, so that work begun from one bench mark may be checked on another.

59. Determining and Adjusting Elevations of Bench Marks.—The elevations of the bench marks of a city, determined by leveling from the primary bench and from other secondary benches, will be more or less inconsistent unless they are carefully adjusted. This adjustment should always be performed. The following illustration will indicate the general method of procedure: Suppose P, Fig. 21, to be the primary bench, the other lettered corners being secondary benches distributed over the city. If the elevations of these benches are consistent, it is evident that, if the difference in

level between A and B, that between B and C, that between C and F, and that between F and A are added algebraically, the sum should be zero. Thus, suppose the several corners to have the following actual elevations: A, 426.421; B, 447.632; C, 450.964; F, 439.672; then, the differences are

$$\begin{aligned} A \text{ to } B,\ 447.632 - 426.421 &= +21.211 \\ B \text{ to } C,\ 450.964 - 447.632 &= +\ \ 3.332 \\ C \text{ to } F,\ 439.672 - 450.964 &= -11.292 \\ F \text{ to } A,\ 426.421 - 439.672 &= -13.251 \\ \text{Sum} &= \quad 00.000 \end{aligned}$$

But suppose that, in leveling around the polygon, the differences found are the following:

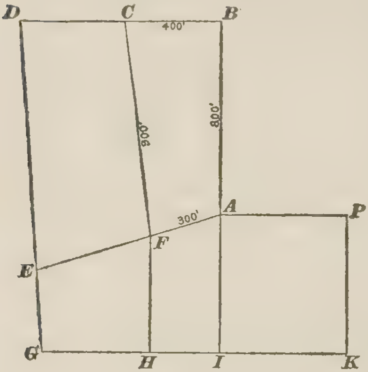


FIG. 21

$$\begin{aligned} A \text{ to } B,\ &+21.200 \\ B \text{ to } C,\ &+\ \ 3.342 \\ C \text{ to } F,\ &-11.271 \\ F \text{ to } A,\ &-13.252 \\ \text{Sum} = &+\ \ 0.019 \end{aligned}$$

Then, if the elevations B, C, and F are determined in order from A, by using these differences, the level of A, determined from F, will differ by .019 from that used to begin with. Similarly, the elevations of the corners of each polygon must be consistent, but will not be so ordinarily, because each is obtained by applying the difference in level between it and its adjacent corners. This error of closure, as it may be called, must be distributed among the several sides so that each polygon shall be consistent. This is called **adjusting the polygon.** There are elaborate methods of adjusting the whole series at once by the use of the method of least squares, but the work is complicated and laborious, and simpler methods produce results of sufficient precision.

60. It may be assumed either that the errors that have been made are proportional to the distances between adjacent

benches, or that they are proportional to the square roots of those distances. The late Prof. J. B. Johnson, who was an authority on precise leveling, advised the square root, which seems to agree better with practical considerations. When a whole system of several polygons is to be adjusted, that one containing the largest error is adjusted first, that containing the next largest error second, and so on. When one or more sides of a polygon to be adjusted are also sides of polygons already adjusted, the adjusted values of those sides are not changed, but the whole error is distributed among the remaining unadjusted sides. Care should be taken in this method that an interior polygon entirely surrounded by other polygons is not the last to be adjusted, as the method may then fail.

The polygon *A B C F*, Fig. 21, is adjusted as indicated in the following table:

Length of Sides	Square Roots of Lengths	Total Error	Proportion	Original Difference	Corrected Difference
A B, 800	28.28		$\frac{.019}{95.60} \times 28.28 = -.006$	+21.200	+21.194
B C, 400	20.00	.019	$\frac{.019}{95.60} \times 20.00 = -.004$	+ 3.342	+ 3.338
C F, 900	30.00		$\frac{.019}{95.60} \times 30.00 = +.006$	− 11.271	−11.277
F A, 300	17.32		$\frac{.019}{95.60} \times 17.32 = +.003$	− 13.252	−13.255
	95.60			+ .019	0.000

The square roots of the lengths are first obtained. The total error is divided by the sum of these roots, and the correction for each difference is found by multiplying the quotient thus obtained by the square root of the corresponding length.

Since the plus differences were too large, they must be diminished, while the minus differences must be increased. Beginning now with the elevation of point *A*, the other points may be determined in either direction around the polygon.

The elevations that result are as follows, assuming that of A to be 426.421:

$$\begin{array}{rr} A = & 426.421 \\ & \underline{21.194} \\ B = & 447.615 \\ & \underline{3.338} \\ C = & 450.953 \\ & \underline{11.277} \\ F = & 439.676 \end{array}$$

It will be observed that these are not the elevations first assumed to be correct, and it is true that they are probably not the true precise elevations, but they are as near to the truth as the nature of the work permits.

In determining the error in the polygon $CDEF$, the corrected difference for the side CF would be used, and the whole error distributed among the three remaining sides.

OFFICE RECORDS

61. Block Books.—For land lines, perhaps the best form of record book is a **block book,** which is large enough to have a single city block drawn on a page, to a scale of from 50 feet to 100 feet to the inch. All records of distances, angles, monuments, etc. obtained from lot or street surveys can be easily shown on the plot in the book. With each block should be shown the relation of its lines to those of the adjoining blocks. The book should be indexed, and should be arranged in some logical order, preferably in some other manner than by wards, which, being political divisions, are subject to change. The blocks may be arranged from south to north or from north to south, and from west to east. This is a good arrangement, since maps of adjoining property will be close together in the book for more convenient reference. The index may be arranged alphabetically by tract or addition, or by some other scheme fitting the conditions in the particular city in which the surveyor works.

These block books are sometimes large, like an atlas, and contain the map of a whole tract or addition on a single page

or on two pages. This has the advantage of showing at a glance the relations of a considerable number of lines; and, as each tract or addition usually has some peculiarities of its own, they appear more clearly on a map of the whole addition showing the relations of street lines outside the addition to those within it.

62. Block Cards.—An excellent system for recording land-line measurements is the card system. A standard filing or index card, 5 in. × 8 in., which is a stock size, is large enough to map most single blocks, and to show the several measurements that may be made from time to time. Such a lot of cards should be arranged logically in the same order as would be used in a block book, and a separate drawer of ordinary cards, 3 in. × 5 in., should be used to index the map or block cards. In a busy office, these cards have the advantage of permitting several persons to work on different blocks at the same time, and they are more readily handled on a desk or table than is a book. By consulting the catalog of any of the filing-cabinet makers, the surveyor will be able to select a suitable set of cards for his purpose.

63. Record Maps.—Copies should be made of the record maps of subdivisions of the various plots, tracts, or additions filed in the office of the custodian of records. These copies should be on tracing cloth, and should be exact copies of everything appearing on the original maps. In a newly established office, the making of these plots should be one of the first duties occupying all the spare time of the office force. The copies need not be of the same size as the original plots, but should rather be of uniform size for convenience in filing. A size governed by the size of local plots, and a scale large enough to permit the clear showing of all dimensions, angles, numbers, etc. should be adopted. These tracing-cloth copies should be filed for record, prints being made on tough thin paper for office and field use. Prints may also be made as wanted for sale to interested persons, such as real-estate dealers, abstract makers, etc. These record maps may be filed in drawers in a filing

cabinet. They should all be numbered with the year of the subdivision record and a serial number; thus, 1896–2, 1896–3, etc. The names of the years covered by the maps may appear on the outside of the drawers containing them. The index, which should be by name of parcel, plot, tract, or addition, would give the year and serial number of the plot, thus insuring its quick location. Or, the drawers may simply be numbered, in which case the index will give the drawer and map number.

The title of the drawings and all lettering should be uniform in size and style. It is not necessary that the plots contain all references and tie-lines to locate corners or monuments, as these will appear in the field books or in the monument books devoted to this purpose.

From time to time, as surveys of lots are made, the date and number of survey may be written in the lot space on the plot.

64. Filing of Maps and Profiles.—Of necessity, continuous profiles of long lines must be rolled, but it is much better to make shorter lengths on sheets that can be filed flat. Moreover, maps to be used for reference, as well as all drawings of plans, should be on sheets of standard size. To get the best results, sheets for filing purposes should be of such a size that they can readily be cut into halves, quarters, etc., without waste, in case smaller cards are desired; and these standard sizes should be strictly adhered to. Thus, a sheet 24 in. × 36 in. will cut into sheets 18 in. × 24 in., 12 in. × 18 in., 9 in. × 12 in., and 6 in. × 9 in., all of which are good filing sizes. Drawing paper 24 in. × 36 in. is made, and is used by many large construction companies, but it is not the commonest size, nor does it fit the drawers of the various filing cabinets now made. Other sizes may be used, or special cabinets may be built for drawings. The drawers should be about $1\frac{1}{2}$ to 2 inches larger in both directions than the sheets to be filed, and from $1\frac{1}{2}$ to 2 inches deep. Drawers deeper than this will hold too many drawings to be conveniently handled in looking for any particular set. Each

drawer should be numbered or lettered, as well as each stack or case; if the drawer is numbered, the stack or case should be lettered, and vice versa.

Profiles that are rolled are perhaps best kept in numbered cylindrical cases with covers. The number is painted on the end, and the cases are filed in racks, with compartments large enough for one or two dozen cases; or they may be filed in drawers made to fit them.

Maps for recording purposes should be on tracing cloth, from which blue or positive prints on tough paper may be made for office and field use.

Alterations, as they are made in the lines represented on any map, may also be put on the tracing and new prints made, when the old ones should be discarded.

65. Private Surveys.—Every survey for an individual, no matter how small or insignificant the survey may be, should have its complete record carefully kept and indexed. Each survey should have a serial number. The notes should always be taken in a field book, never on a scrap of paper, and these notes should bear the date and number of the survey, the names of the surveyor and his assistants, a brief record of any pertinent conversation held concerning the survey, the time of day, and the general condition of the weather, besides the usual notes of measurement for angles, tie-lines, etc. Many such notes seem trivial in the extreme, and some of them are never seen a second time, but occasionally unexpected litigation arises that makes them of the greatest value to the surveyor acting as an expert witness. Their value at such times will frequently, for even a single court case, far exceed the cost of making complete notes for all the surveys of a whole year. The index of the notes should be double, under the owner's name or the name of the person for whom the survey is made, and again under the block, tract, addition, or street number or name.

66. Field Books.—In the field book, the notes of more than one survey or measurement should never appear on one page. The notes of a single survey or series of measure-

ments for a single purpose may extend over several pages, but many surveys are exceedingly simple; as, for instance, the measurement of the distance from a saloon to a church or school in an excise case, the measurement of the height of a dam, a wall, the dimensions of a cross-walk, the length of a private sewer, or the like, which might require one or two lines only of a book, or might be considered to be so trivial as to make a written note of the work superfluous. Nevertheless, the notes of any such measurements should be given a separate page in the notebook, when the miscellaneous notes of weather, assistant, date, hour, etc. will occupy more space than the simple memorandum of the work done. The field book should be indexed on one or two of the back or front pages; while a simple table of contents should be entered as the notes are taken, and a separate alphabetical index made when the book is full.

67. Card Index.—A card index should be kept of all records of surveys, and of all maps or drawings in the surveyor's office. The index should be by streets, blocks, tracts, additions, sections, or other land division—never by political divisions. The card index may be divided into sections; such as, private surveys, street surveys and maps, sewer surveys and maps, waterworks surveys and maps, etc. If there are field notes, a profile and a map of a given survey—such, for example, as a street survey—all these should appear on the proper index card, which should indicate the number and page of the field book, the number and drawer or compartment or case of the profile or map, and the date of the particular survey under consideration. Each surveyor will devise a scheme of indexing adapted to his needs.

68. Monument Records.—In the office there should be several bench-mark books containing a list of the bench marks in the city, with their elevations and a description of the marks so clearly written that any one may find them. Any party in the field should have with it a bench-mark book. The list should be put in the book by streets, for ready reference. Similarly, there should be several books